U.S. ARMY
MATERIEL COMMAND

U.S. ARMY
TEST AND EVALUATION
COMMAND

AD No. ______________

TECOM Project No. 7-CO-M95-AVD-004

FINAL REPORT

METHODOLOGY INVESTIGATION

GLOBAL POSITIONING SYSTEM (GPS) VEHICLE TRACKING SYSTEM FOR FLIGHT TESTING OF FIXED- AND ROTARY-WING AIRCRAFT

MR. LARRY MARTIN, TEST DIRECTOR/ENGINEER

UNITED STATES ARMY AVIATION TECHNICAL TEST CENTER
FORT RUCKER, ALABAMA 36362-5276

JUNE 1996

Period Covered:
June 1995 - April 1996

Prepared for:
Commander
U.S. Army Test and Evaluation
Command
ATTN: AMSTE-CT-T
Aberdeen Proving Ground, MD
21005-5055

Approved for public release;
distribution is unlimited.

U.S. Army Test and Evaluation Command
Aberdeen Proving Ground, MD 21005-5055

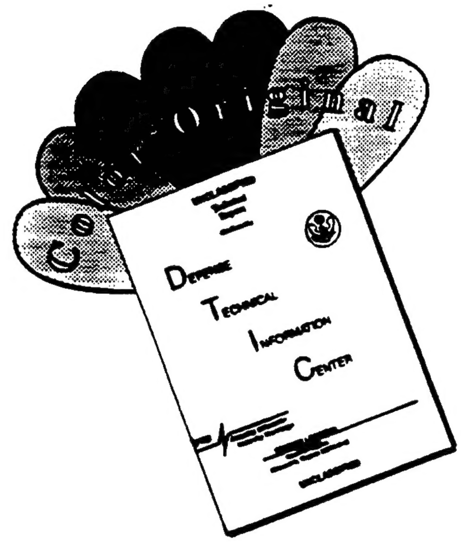
Destruction Notice

Destroy this document when no longer needed. Do not return to the originator. Destroy by any method that will prevent disclosure of contents or reconstruction of the document.

Trade Names Statement

The use of trade names in this document does not constitute an official endorsement or approval of the use of such commercial hardware or software. This document may not be cited for purposes of advertisement.

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005-5055

REPLY TO
ATTENTION OF

AMSTE-TM-T (70-10p) 26 Aug 96

MEMORANDUM FOR Commander, U.S. Army Aviation Technical Test Center, ATTN: STEAT-TS-D, Fort Rucker, AL 36362-5276

SUBJECT: Final Report, Methodology Investigation, Global Positioning System (GPS) Vehicle Tracking System for Flight Testing of Fixed- and Rotary-Wing Aircraft, TECOM Project No.7-CO-M95-AVD-004

1. Subject report is approved.

2. The TECOM point of contact is Mrs. Cyndie McMullen, AMSTE-TM-T, amstectt@apg-9.apg.army.mil, DSN 298-1469.

FOR THE COMMANDER:

for C. DAVID BROWN, Ph.D.
Chief, Simulation & Technology Division
Directorate for Technical Mission

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (leave blank)	**2. REPORT DATE** 9606	**3. REPORT TYPE & DATES COVERED** Methodology Investigation, 9506-9604

4. TITLE & SUBTITLE Methodology Investigation, Global Positioning System (GPS) Vehicle Tracking System for Flight Testing of Fixed- and Rotary-Wing Aircraft	**5. FUNDING NUMBERS**
6. AUTHOR(S) Mr. Larry Martin, Test Director/Engineer, DSN 558-8276, Commercial (334) 255-8276	
7. PERFORMING ORGANIZATION NAME(S) & ADDRESS(ES) U.S. Army Aviation Technical Test Center ATTN: STEAT-TS-D Fort Rucker, AL 36362-5276	**8. PERFORMING ORGANIZATION REPORT NUMBERS** 7-CO-M95-AVD-004
9. SPONSORING/MONITORING AGENCY NAME(S) & ADDRESS(ES) Commander U.S. Army Test and Evaluation Command ATTN: AMSTE-CT-T Aberdeen Proving Ground, MD 21005-5055	**10. SPONSORING/ MONITORING AGENCY REPORT NUMBER** 7-CO-M95-AVD-004
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE**

13. ABSTRACT (Maximum 200 words) The U.S. Army Aviation Technical Test Center (ATTC) conducted the methodology investigation of the global positioning system (GPS) vehicle tracking system at White Sands Missile Range from June 1995-April 1996. The objectives were to quantify the accuracy of the GPS tracking system throughout the dynamics of normal helicopter flight and ensure that the rotor effect on the GPS signal reception is considered. It was concluded that the system as tested is capable of tracking helicopters through their flight envelope to an accuracy of less than 2 feet spherical error probable in real time, and the rotor system appeared to have little effect on the GPS signals.

14. SUBJECT TERMS Methodology Investigation Global Positioning System (GPS) Time Space Positioning Information (TSPI) Truth Data Acquisition Recording and Display System (TDARDS)	**15. NUMBER OF PAGES** 72
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	**18. SECURITY CLASSIFICATION OF THIS PAGE** UNCLASSIFIED	**19. SECURITY CLASSIFICATION OF ABSTRACT** UNCLASSIFIED	**20. LIMITATION OF ABSTRACT**

NSN 7540-01-280-5500 Standard Form 298

TABLE OF CONTENTS

FOREWORD

The U.S. Army Aviation Technical Test Center (ATTC) was responsible for planning, execution, and reporting of this methodology investigation.

All data for this report are filed at ATTC under TECOM Project No. 7-CO-M95-AVD-004.

ATTC gratefully acknowledges the contributions of the following personnel to this study:

Mr. Antonio Palomino, White Sands Missile Range
Mr. Mark Moeglein, Stanford Research Institute

SECTION 1. SUMMARY

1.1 BACKGROUND

The U.S. Army Aviation Technical Test Center (ATTC), jointly with White Sands Missile Range (WSMR), developed a global positioning system (GPS) vehicle tracking system. ATTC uses the tracking system in flight testing to provide time space positioning information (TSPI) of fixed- and rotary-wing aircraft. The GPS tracking system, named the Truth Data Acquisition Recording and Display System (TDARDS), was designed to be a real-time tracking system capable of 1-meter root mean square (RMS) spherical error probable (SEP). TDARDS consists of a vehicle system or systems (up to 10 units), a ground system, and a data link. The TDARDS uses differential GPS technology with both carrier phase and code measurements to provide the very accurate position solution.

1.2 PROBLEM

Determine the baseline accuracy of the TDARDS so that ATTC can use the TDARDS in flight testing as a TSPI truth source.

1.3 OBJECTIVES

1.3.1 Quantify the accuracy of the TDARDS GPS tracking system throughout the dynamics of normal helicopter flight.

1.3.2 Ensure that the rotor effect on the GPS signal reception is considered.

1.4 PROCEDURES

1.4.1 ATTC conducted the accuracy measurement test at WSMR from June 1995 through April 1996. A UH-60L BLACKHAWK helicopter was used as the airborne platform, and the airborne GPS was mounted in the rear of the cargo area of the aircraft. The test was confined to a small area on the WSMR and optical tracking systems at WSMR were used as the truth data. All data produced in the report are with respect to the WSMR truth data.

1.4.2 Mounting of the GPS vehicle unit required mounting the GPS receiver antenna, GPS receiver, and data link antenna. Since the GPS antenna would be the tracking target used by WSMR optics, care was taken to ensure maximum visibility around the helicopter fuselage. The GPS antenna was mounted where the main fuselage and the tailboom meet, approximately 216 inches aft of the main rotor hub on the center line of the aircraft. The mount was a white rectangle 8 inches wide by 8 inches tall that affixed to the top of the tail rotor drive shaft cover. Six white stripes

were painted on each side of the airframe in an arrow shape pointing to the GPS antenna mount (figure (fig.) 1). The GPS receiver was mounted on the aircraft floor in the rear center of the cargo area. The data link antenna was mounted on the bottom of the aircraft on a cover made to fit over the cargo hook hole.

1.4.3 The GPS ground station consisted of two computers that were interconnected, a GPS reference receiver card, a GPS antenna, a data link transmitter, and a data link antenna. One of the computers was used to collect GPS data to correct the vehicle unit GPS, and the other computer was used to control the data link to the vehicle unit GPS.

1.4.3.1 To properly set up the GPS reference receiver computer, the GPS antenna had to be located over a first order surveyed point less than 30 meters away from the GPS reference receiver. The point at WSMR was on the roof of building 300. The location of the point was surveyed just prior to the testing.

1.4.3.2 The data link computer was located in building 300 directly adjacent to the reference receiver computer. The antenna for the data link computer was also located on the roof of building 300.

1.4.4 The optical trackers (cinetheodolites) at WSMR were located on the "Small Missile Range" in a rectangular pattern (fig. 2). There were two parallel rows of 3 trackers each; the rows were separated by approximately 7,000 feet, and the individual trackers in each row were 4,000 feet apart. A 2,500- by 6,000-foot box was centered and overlaid on the area of the trackers in which the aircraft maneuvers were completed.

1.4.5 The test was flown in accordance with (IAW) the test plan (appendix (app) A). Start times and stop times (app B) were determined when the helicopter entered and exited the maneuver box.

1.4.6 The test did not begin until the reference receiver indicated a GPS constellation of at least four satellites.

1.4.7 The GPS data to be collected were the raw measurements data (pseudorange, range rate, integrated carrier cycles, and integrated carrier phase) on board the vehicle and ground station for postmission processing (referred to as method 3) and the navigation solution (latitude, longitude, altitude) generated in the vehicle unit using the differential corrections generated by the ground station (referred to as method 1).

FIGURE 1. WHITE STRIPES POINTING TO WHITE GPS ANTENNA MOUNT

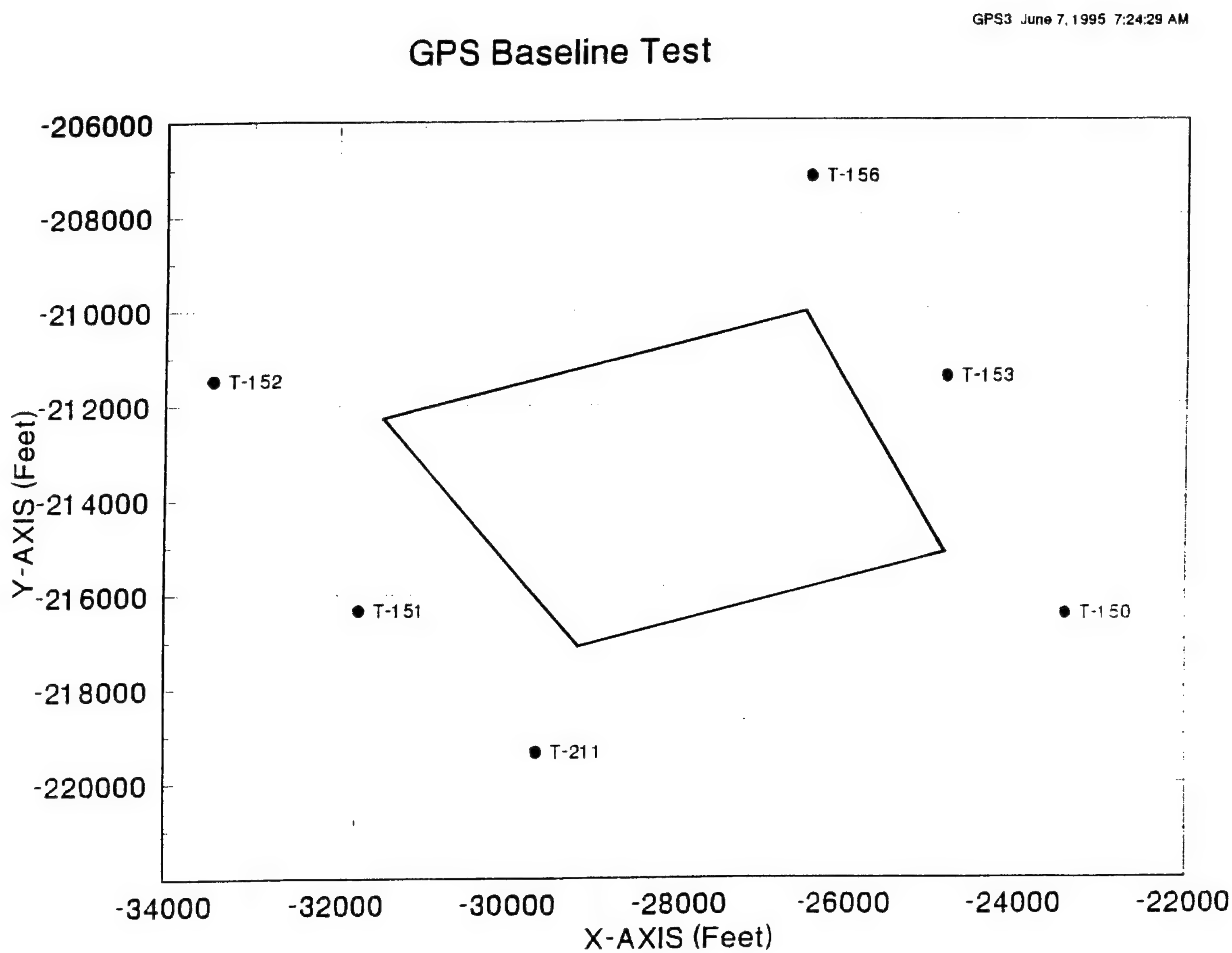


FIGURE 2. PATTERN OF OPTICAL TRACKERS AND MANEUVERING BOX

1.4.7.1 The postmission-processed GPS data used a process referred to as carrier averaging to produce the navigation solution from the raw measurements taken at the vehicle unit and ground station. The carrier averaging process was applied to the GPS receiver channel by channel (or satellite by satellite). Pseudorange and integrated carrier phase corrections were calculated by using the reference receiver data and the first order survey data and were individually applied to the airborne GPS receiver's code and carrier measurements. Once these corrections were applied, the difference between pseudorange and integrated carrier phase measurements was observed. The weighted average of this difference over the entire interval for which the satellite vehicle was in track determined the best estimate for the constant of carrier phase integration. On a second pass through the data, the stored constant of integration was added to the individual integrated carrier phase samples to form the best estimate of pseudorange. This best estimate of pseudorange data was then used in determining position (or a navigation solution) using a weighted least squares filter. Finally, this position solution was smoothed with differentially corrected velocity data, which were also derived from integrated carrier phase data.

1.4.7.2 The real-time navigation solution was calculated by using the pseudorange and integrated carrier phase differential corrections received from the ground station at the airborne GPS and individually applied to the GPS receiver's pseudorange and integrated carrier measurements. Once these corrections were applied, the difference between pseudorange and integrated carrier phase measurements was observed. The weighted average of this difference over the time the satellite vehicle had been in track (past data only) was used as an estimate for the constant of carrier phase integration. This constant was added to the most recent integrated carrier phase sample to form the best estimate of pseudorange. This best estimate of pseudorange data was then used in determining position (or the navigation solution) using a weighted least squares filter. (Note that the real-time (method 1) software does not currently perform the velocity smoothing found in the postmission (method 3) software.)

1.5 RESULTS

1.5.1 The GPS antenna installation on the UH-60L tailboom proved to be very effective for the WSMR test. The antenna provided a highly visible target from all aspect angles of the helicopter. The white-painted antenna mount also had a high contrast that was easily identifiable through the optical tracker video. The added stripes painted on the tailboom of the helicopter pointing to the antenna were visually helpful. The GPS antenna was mounted on the tailboom under the rotor, approximately two-thirds of the way down the rotor. This ensured that the GPS data were exposed to the interference problems associated with the rotor.

1.5.2 The reference receiver ground station could not be set up to operate in the method 1 mode of position solution (differential corrections transmitted to the aircraft and the position solution calculated on the aircraft and transmitted to the ground station). This turned out to be caused by a setup problem with the third RS-232 port on the ground station. This port is used to communicate with a graphics system for displaying position. The method 3 mode of GPS position solution (airborne GPS raw measurements are transmitted to the ground station where they are corrected using the reference receiver corrections and a position solution is calculated on the ground station) was used for real-time operation. Data presented in this report as real time used the algorithms that would have been used on the airborne unit for method 1 processing. These data were processed postmission and are a representation of what the data would have been assuming a perfect transmission data link with no data dropouts. For most applications where there is line of sight between the ground station and the airborne unit, this is a safe assumption.

1.5.3 Although some maneuvers were not completed within the smaller prescribed box inside the optical trackers, all were completed within the larger rectangle formed by the trackers (fig. 2).

1.5.4 The helicopter performed the maneuvers IAW the test plan. These maneuvers were increasingly more dynamic and gave a trend of the effects of the dynamics on the GPS solution.

1.5.5 The constellation of GPS satellites viewable by both the ground station and the airborne GPS varied between 6 and 9. The solution switched between satellites during the dynamic maneuvers, but the transitions occurred without dropping below the 6 common satellites.

1.5.6 The data comparing the postmission and real-time processed GPS position solution to the WSMR optics data are summarized in app C and D, respectively. A summary of statistics for the postmission and real-time processed data is in app E.

1.6 CONCLUSIONS

1.6.1 The TDARDS is capable of tracking helicopters through their flight envelope to an accuracy of less than 2 feet SEP in real time. The TDARDS solution can be refined in postmission processing to an accuracy of less than 1 foot SEP. It should be noted that the accuracies stated are dependent on having satellite coverage equivalent to the test data or better.

1.6.2 The rotor system appeared to have minimal effect on the GPS signals. There was no difficulty in signal tracking or acquisition, and there was no appreciable carrier-to-noise loss due to the GPS antenna being located under the rotor.

SECTION 2. APPENDIXES

APPENDIX A. METHODOLOGY INVESTIGATION PLAN AND DIRECTIVE

STEAT-FS-B (70-10r) 13 JUN 1994

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Internal Test Plan (Support), Global Positioning System (GPS), TECOM Project No. 4-CO-210-000-068, XO 399

1. REFERENCES

a. Memorandum, Department of the Air Force, Aeronautical Systems Center, 5 May 1994, subject: Customer Test Request, U.S. Army Aviation Technical Test Center.

b. Telephone Conversation, Mr. Rigler, AMSTE-TA-L, Headquarters, U.S. Army Test and Evaluation Command (HQ TECOM), and Mr. Hamilton, STEAT-TS-P, U.S. Army Aviation Technical Test Center (ATTC), 31 May 1994, subject: Support for GPS Test.

c. Technical Manual (TM) 55-1520-237-10, Operator's Manual for UH-60A through UH-60L Helicopters, 15 February 1993.

2. TEST OBJECTIVES

Support the helicopter GPS test program conducted by the Eglin Air Force Base (AFB), Florida (FL), Range Applications Joint Program Office (RAJPO) to:

a. Quantify the effect of rotor blade interference with GPS receiver operation.

b. Determine a suggested location of the GPS antenna for future helicopter use.

3. TESTING AUTHORITY

a. On 5 May 1994, the U.S. Air Force (USAF) Aeronautical Systems Center requested HQ TECOM to direct ATTC to support the Eglin AFB RAJPO as required for the GPS test (reference (ref) paragraph (para) 1a).

b. On 31 May 1994, HQ TECOM directed ATTC to support the GPS test as requested (ref 1b).

4. SYSTEM DESCRIPTION

The instrumentation to be installed on the UH-60A consists of the GPS Coarse Acquisition Code Receiver (CACR), a GPS antenna, a High Dynamics Instrumentation System (HDIS) GPS receiver with solid-state recorder, a RAJPO Data Link System (DLS), a DLS antenna, and a radar tracking transponder and antenna.

5. TEST CONCEPT/PROCEDURE

a. The flight testing will be conducted at Eglin AFB, FL, from 13 June to approximately 17 June 1994. One UH-60A helicopter will be ferried from Cairns Army Airfield (AAF), Fort Rucker, Alabama (AL), to Eglin AFB, FL. Upon arrival at Eglin AFB, the test equipment for the GPS project will be ground checked. DynCorp will provide aircraft staging and maintenance support at Eglin AFB which is several miles from the test site at Eglin range B70.

b. The test will be conducted in approximately 6 flight-hours under day visual meteorological conditions (VMC). Ferry flights to and from the test site (if required) may be completed during day or night VMC or instrument meteorological conditions (early takeoffs and late returns).

c. The flight portion of the test will be conducted at the Eglin AFB test range. The profiles consist of standard maneuvers, shown in table 1, in a specified area of the range. As the helicopter flies the profiles and GPS signal data are acquired and recorded, cinetheodolites and ground-based range radars will track the helicopter location and provide truth data.

Table 1. Flight Maneuvers for GPS Test

MANEUVERS	Altitudes (ft AGL)	Airspeed (KIAS)	Bank Angle (Deg)	Load Factor (g)
1. Racetrack	500	70	30-45	<2.0
2. Figure-8	500	70	30-45	<2.0
3. Vertical takeoff (100-ft increments)	500	TBD	0	<2.0
4. Maximum vertical climb	500	TBD	0	<2.0
5. Medium vertical climb	500	TBD	0	<2.0
6. High speed run	500	120-130	0	<2.0
7. Rapid altitude change in flight	100-300	100-110	0	<2.0

Notes: AGL - above ground level
Deg - degrees
ft - feet
g - gravity
KIAS - knots indicated airspeed
TBD - to be determined

6. ADMINISTRATION AND SUPPORT REQUIREMENTS

a. ATTC will provide one UH-60 helicopter and flightcrew.

b. DynCorp will provide maintenance support at Eglin AFB and Cairns AAF as required. If this test is done on a TDY basis, the DynCorp support crew will consist of a flight mechanic, an electrician, and a technical inspector.

c. The 46th Test Wing (46TW) at Eglin AFB will provide test management and coordination of the overall test effort.

d. The test equipment suite (para 4) will be provided by RAJPO and installed by Dyncorp technicians at Cairns AAF. ATTC will conduct flight release inspections and provide a flight release for the internal sensor package installation.

e. USAF personnel and contractor personnel from Eglin AFB will be flying in the aircraft during the test as test instrumentation operators.

f. The aircraft will be flown without the external stores support system. Crew will consist of two pilots, one crew chief, and up to two instrumentation technicians. With the test equipment installed, the takeoff gross weight will be approximately 15,000 pounds.

g. The aircraft will be flown within the limitations of the UH-60 Operator's Manual (ref 1c) and the flight release.

h. Labor and flight-hours will be charged to XO 399.

i. ATTC will submit a test record within 35 days of test completion.

j. The overall level of risk for this test support is LOW (III-E).

7. POINT OF CONTACT

Point of contact is CW5 William R. Murphy, Test Director, DSN 558-8167, commercial (205) 255-8167, or FAX (205) 255-8174, Fort Rucker.

FOR THE COMMANDER:

JOHN V.R. REDINGTON
LTC, AV
Director, Flt Sys Test Directorate

DISTRIBUTION:
C, PLANS AND SECURITY DIVISION (Mr. HAMILTON)
CW5 MURPHY, TEST DIRECTOR (2 COPIES)
C, FLIGHT TEST DIVISION B
SAFETY OFFICE
C, FLIGHT OPERATIONS DIVISION
MS. MATTHEWS, SENIOR EDITOR
TECHNICAL LIBRARY (5 COPIES)
SECRETARY, FST DIRECTORATE
(RECORD SET/RHA COPY)

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005-5055

REPLY TO
ATTENTION OF

AMSTE-CT-T (70-10p)

[illegible] JUN 1995

MEMORANDUM FOR Commander, U.S. Army Aviation Technical Test Center, ATTN: STEAT-TS-P, Fort Rucker, AL 36362-5276

SUBJECT: Amendment 2 to Test Execution Directive, FY95 Methodology Program

1. Reference HQ TECOM Memo, AMSTE-CT-T, 12 Sep 94, subject: Test Execution Directive, FY95 Methodology Program.

2. This memorandum, with list of projects at enclosure 1, amends reference 1.

3. Point of contact at this headquarters is Ms. Cyndie McMullen, AMSTE-CT, amstect@apg-9.apg.army.mil, DSN 298-1469.

FOR THE COMMANDER:

Encl

Frederick D. Mabanta

FREDERICK D. MABANTA
Chief, Technology Development Division
Directorate for Corporate Information
and Technology

CF:
Cdr, USAATTC, ATTN: STEAT-TS-D (Larry Eagerton)

FY95 METHODOLOGY PROGRAM

AVIATION TECHNICAL TEST CENTER

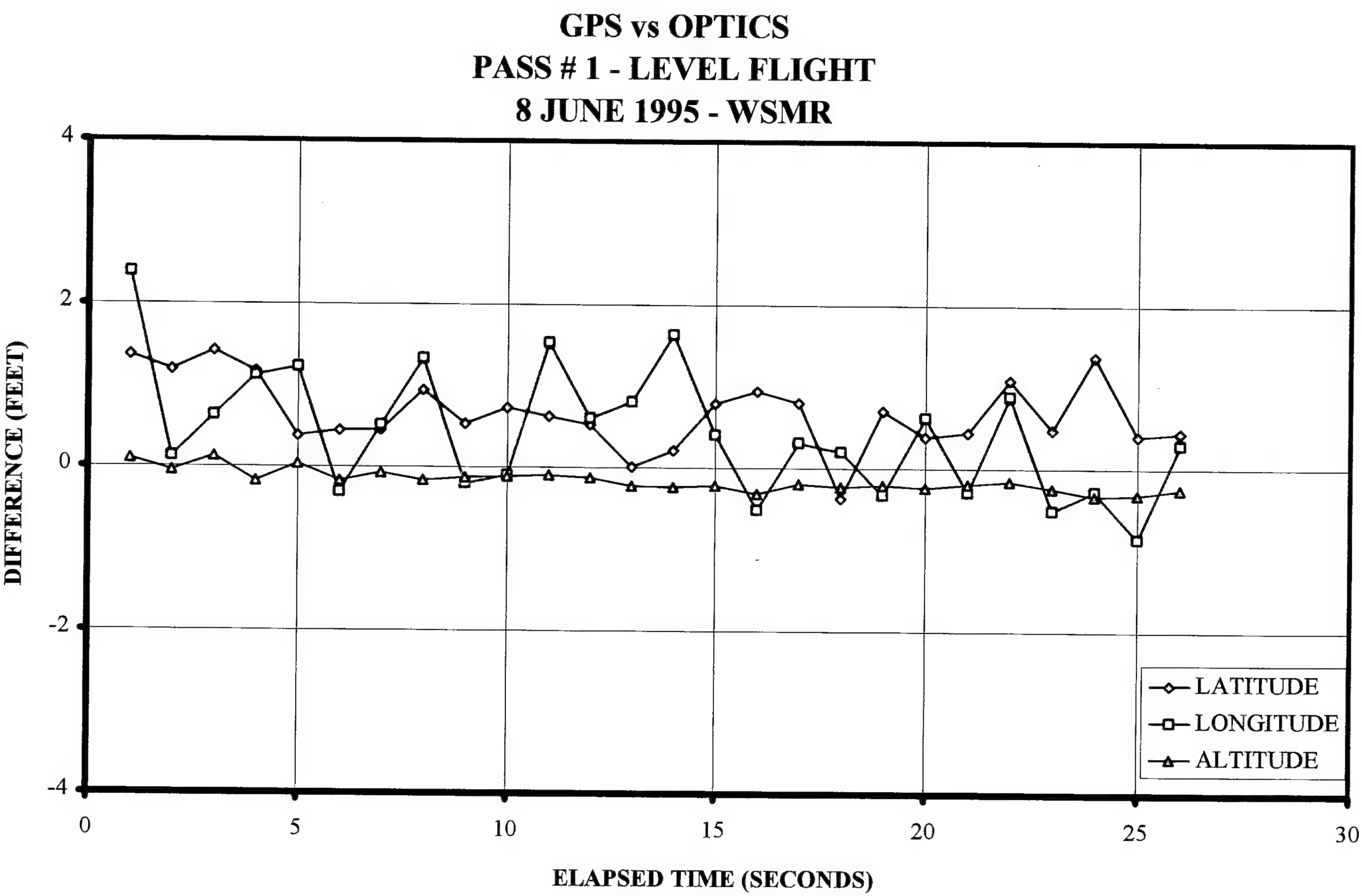
		INITIAL FUNDING	REVISED FUNDING	AMEND #1 24JAN95	AMEND #2 15JUN95
7-CO-M95-AVD-001	FY95 Quick Reaction Methodology	20.0	5.0	-15.0	0.0
7-CO-M95-AVD-002	FY95 Technical Committee Support	5.0	5.0	0.0	0.0
7-CO-M95-AVD-003	Common Airborne Instrumentation Testing	100.0	0.0	-100.0	0.0
7-CO-M95-AVD-004	GPS System Investigation	0.0	80.0	65.0	15.0
		----	----	---	---
	TOTAL ATTC PROGRAM	125.0	90.0	-50.0	15.0

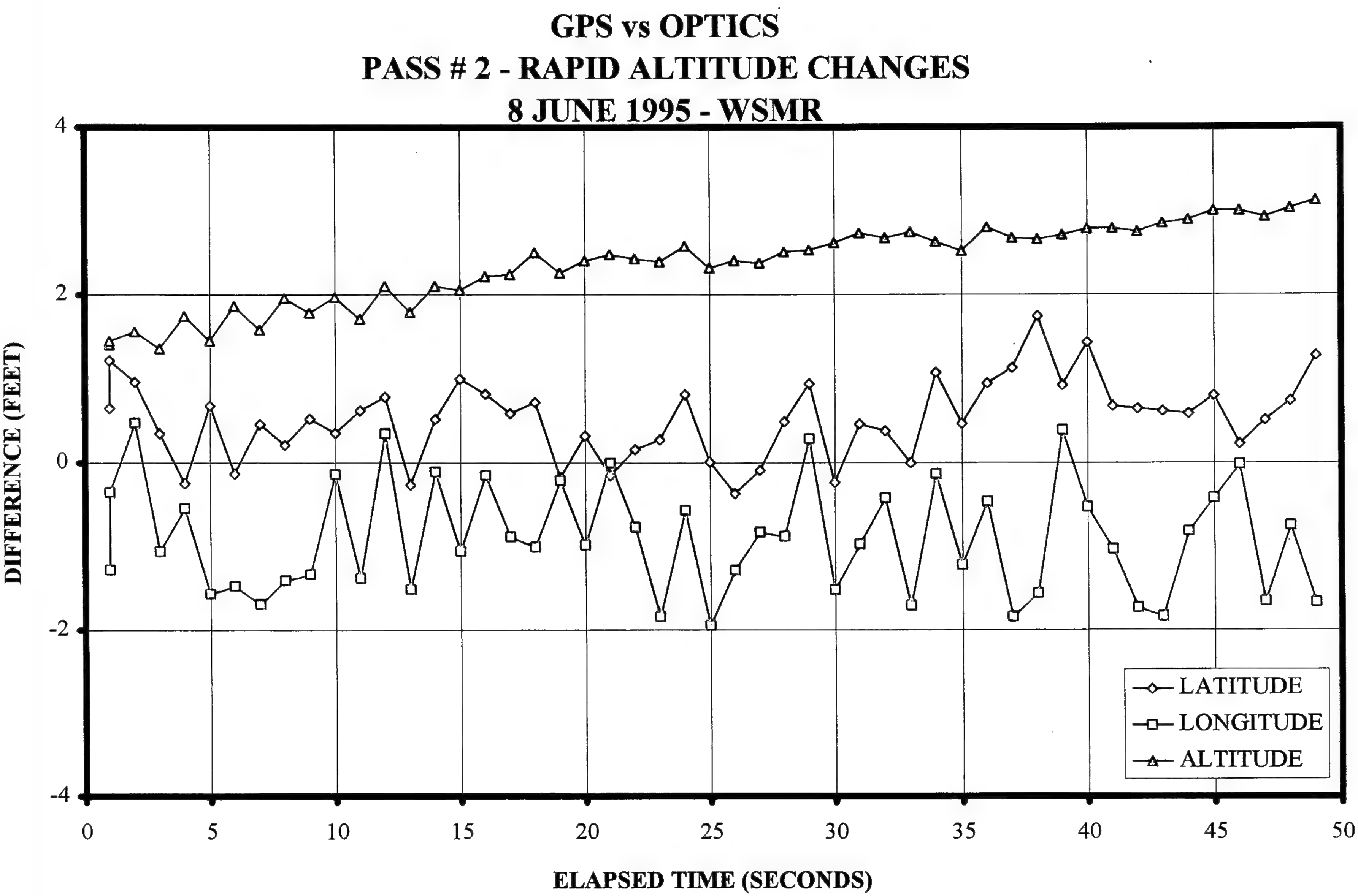
APPENDIX B. START AND STOP TIMES

Following are the start and stop times (Greenwich mean time (GMT)) for each data pass on 8 June 1995. Times are shown in the following sequence: Julian date:hours:minutes:seconds.

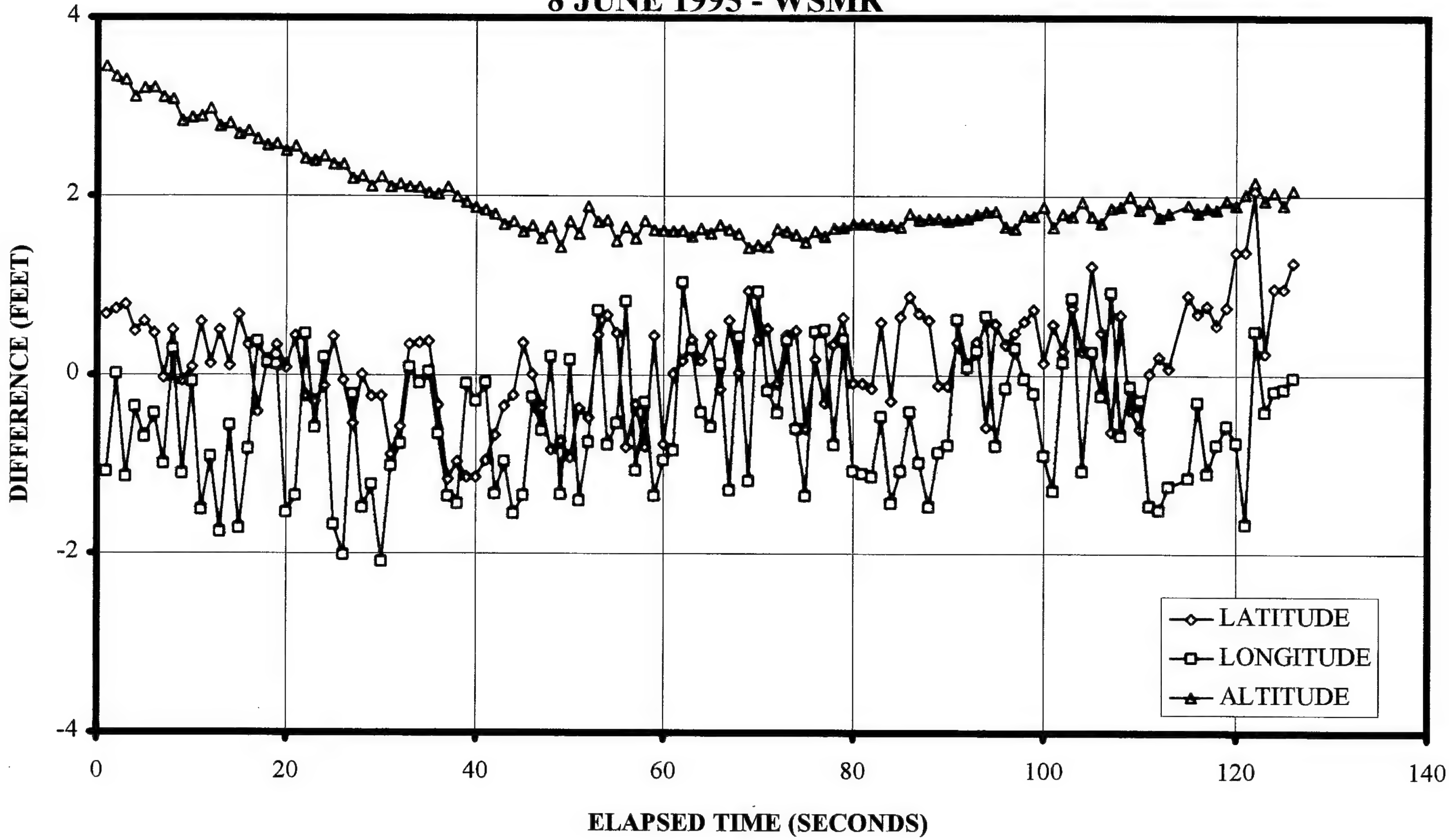
PASS	MANEUVER	START	END
1	Level Flight	5159:18:18:50	5159:18:19:17
2	Rapid Altitude Change	5159:18:20:21	5159:18:21:12
3	15° Bank	5159:18:23:14	5159:18:25:21
4	30° Bank	5159:18:26:34	5159:18:28:10
5	45° Bank	5159:18:29:22	5159:18:30:40
6	60° Bank	5159:18:31:48	5159:18:32:53
7	Figure 8	5159:18:34:12	5159:18:36:00
8	Level Flight	5159:18:37:16	5159:18:37:48
9	Rapid Altitude Change	5159:18:39:13	5159:18:39:51
10	Level Flight	5159:18:41:16	5159:18:41:43
11	15° Bank	5159:18:43:12	5159:18:44:55
12	30° Bank	5159:18:46:48	5159:18:48:05
13	45° Bank	5159:18:49:47	5159:18:50:47
14	60° Bank	5159:18:52:02	5159:18:53:00
15	Figure 8	5159:18:54:11	5159:18:55:09
16	Level Flight	5159:18:57:02	5159:18:57:29
17	Rapid Altitude Change	5159:18:59:15	5159:18:59:58
18	Level Flight	5159:19:01:34	5159:19:02:03
19	15° Bank	5159:19:04:31	5159:19:06:19
20	30° Bank	5159:19:08:20	5159:19:09:41

APPENDIX C. COMPARISON OF POSTMISSION GPS POSITION SOLUTION TO WSMR OPTICS DATA

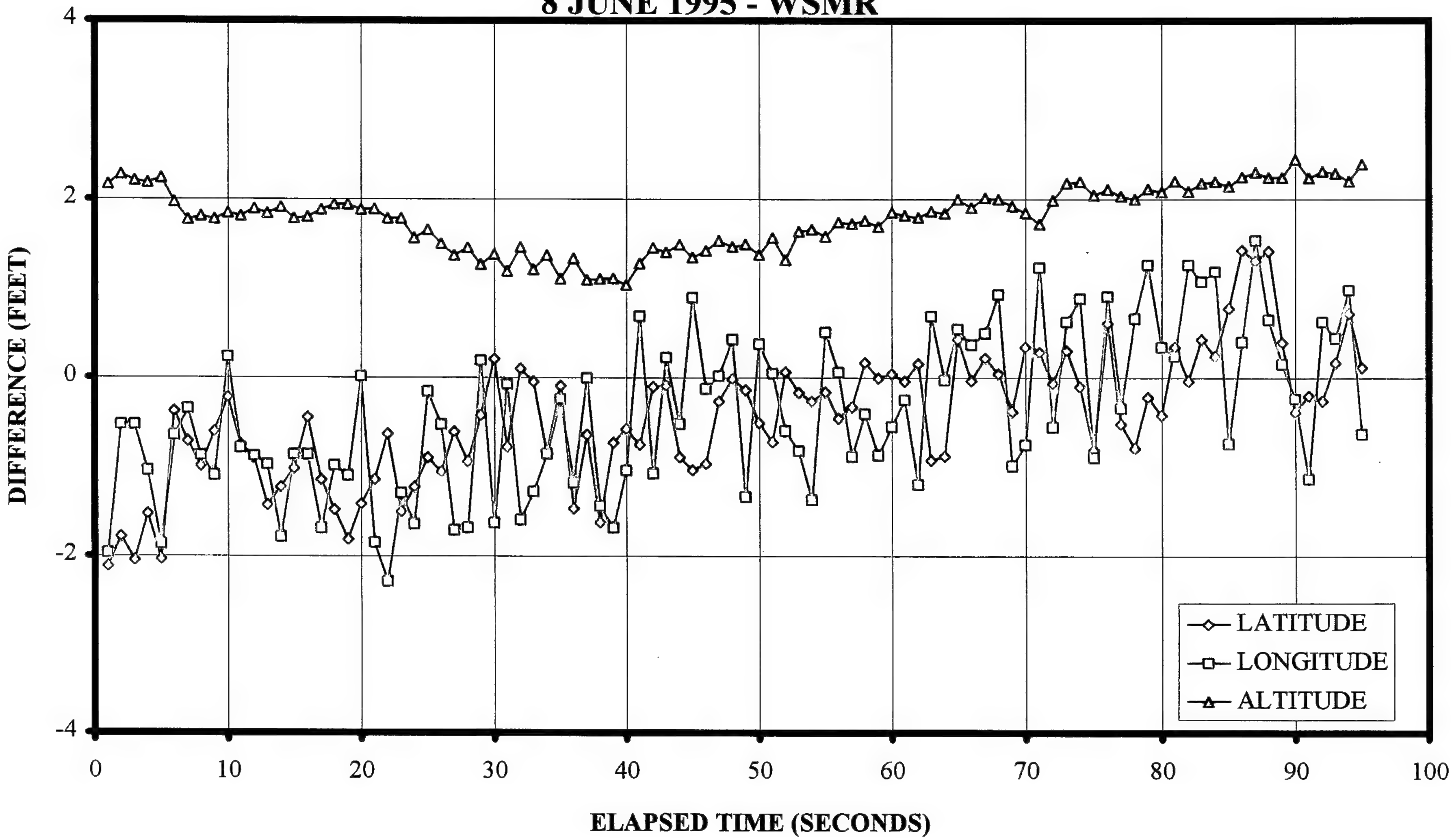

GPS vs OPTICS
PASS # 1 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE
4
2
0
-2
-4
0
5
10
15
20
25
30


GPS vs OPTICS
PASS # 2 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
35
40
45
50
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

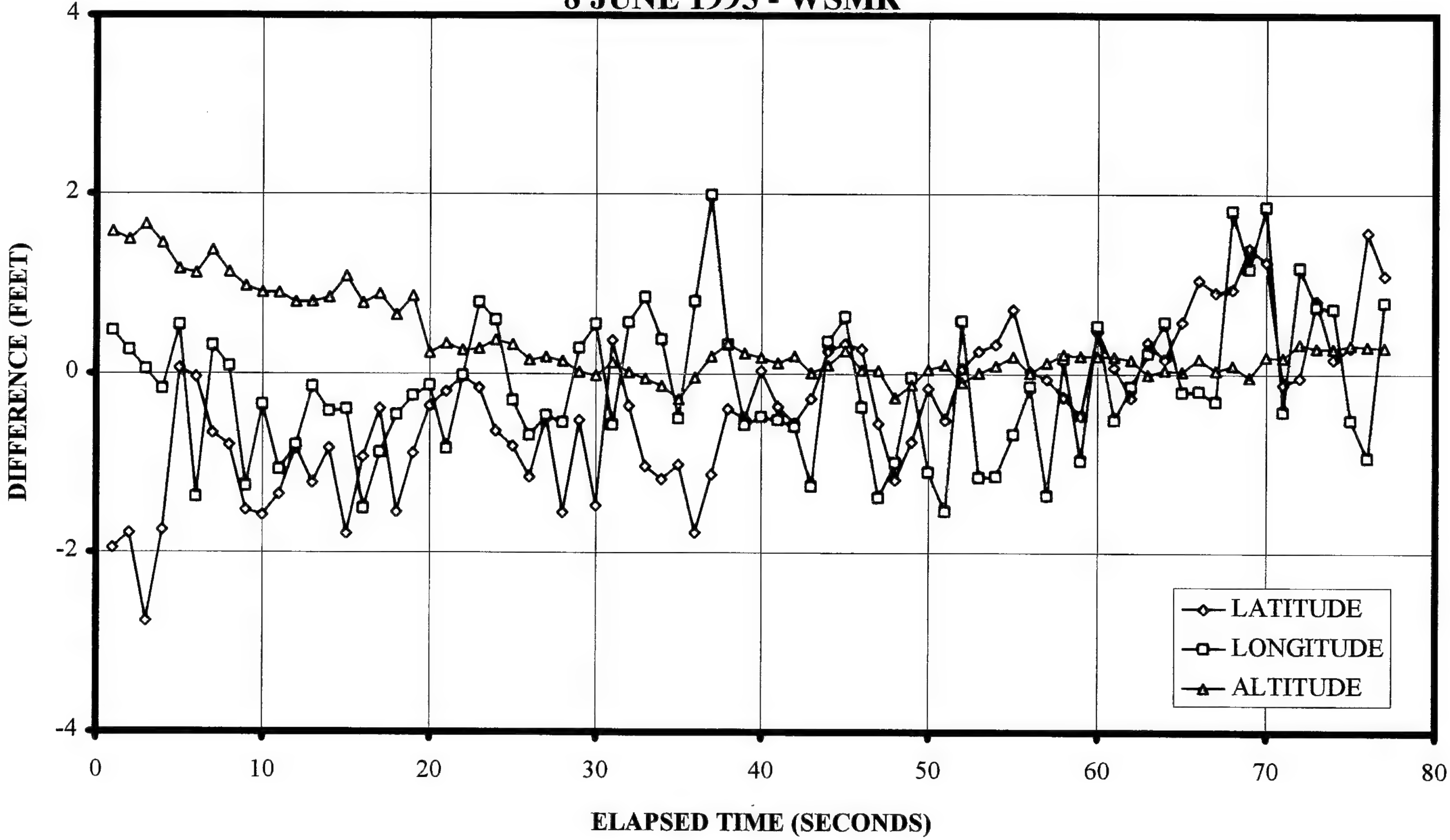
GPS vs OPTICS
PASS # 3 - 15 DEGREE BANK
8 JUNE 1995 - WSMR

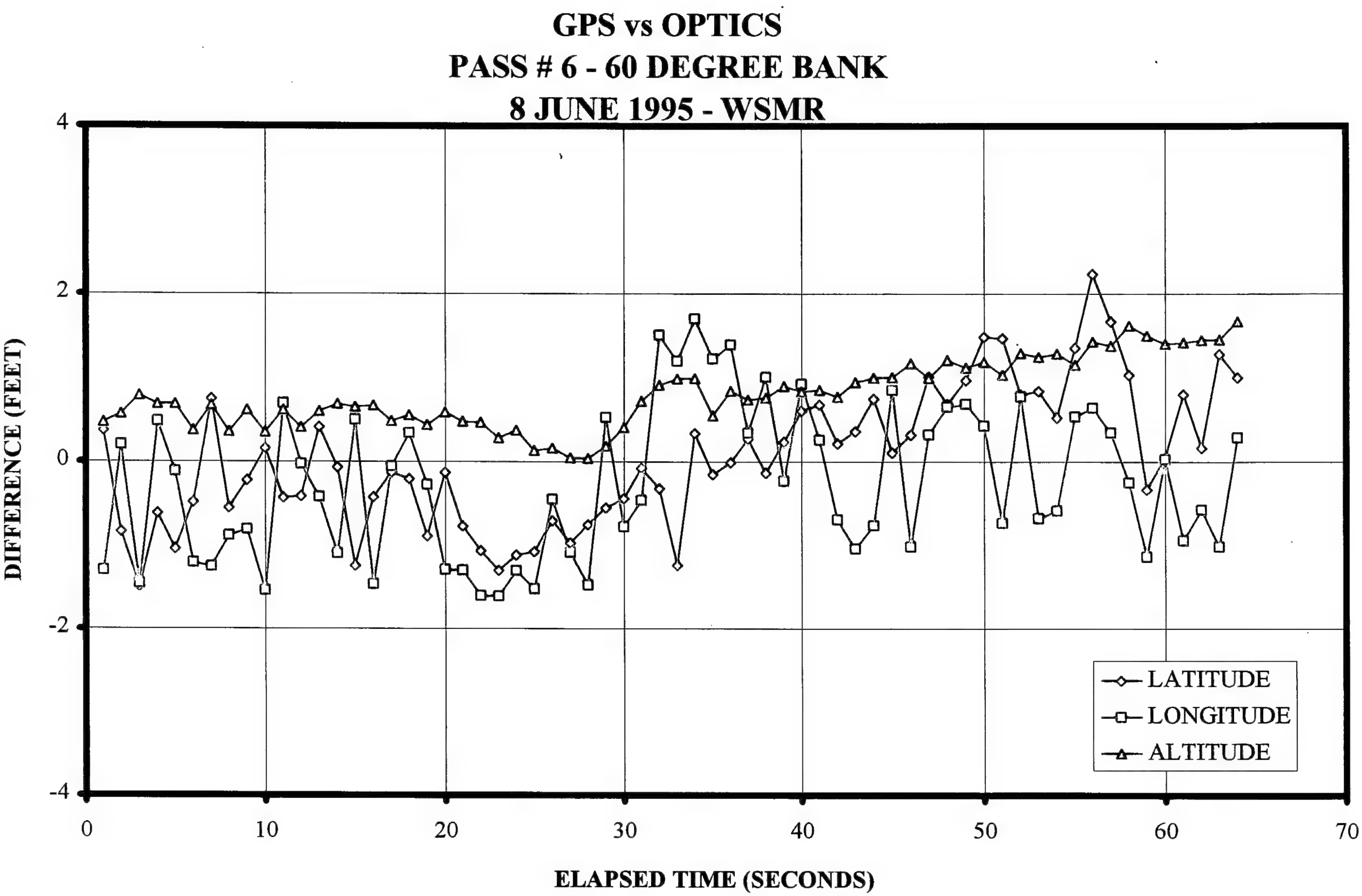


GPS vs OPTICS
PASS # 4 - 30 DEGREE BANK
8 JUNE 1995 - WSMR

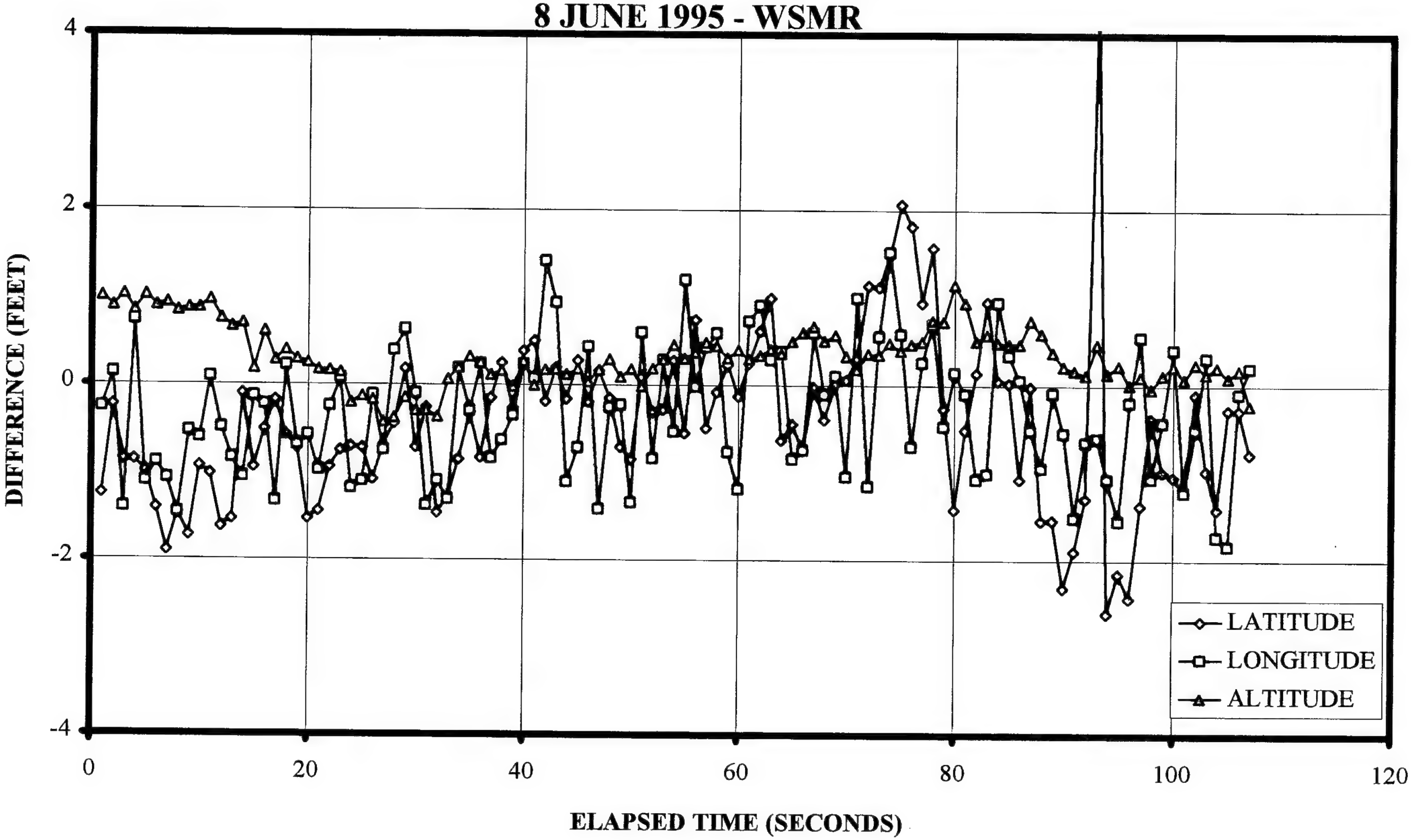


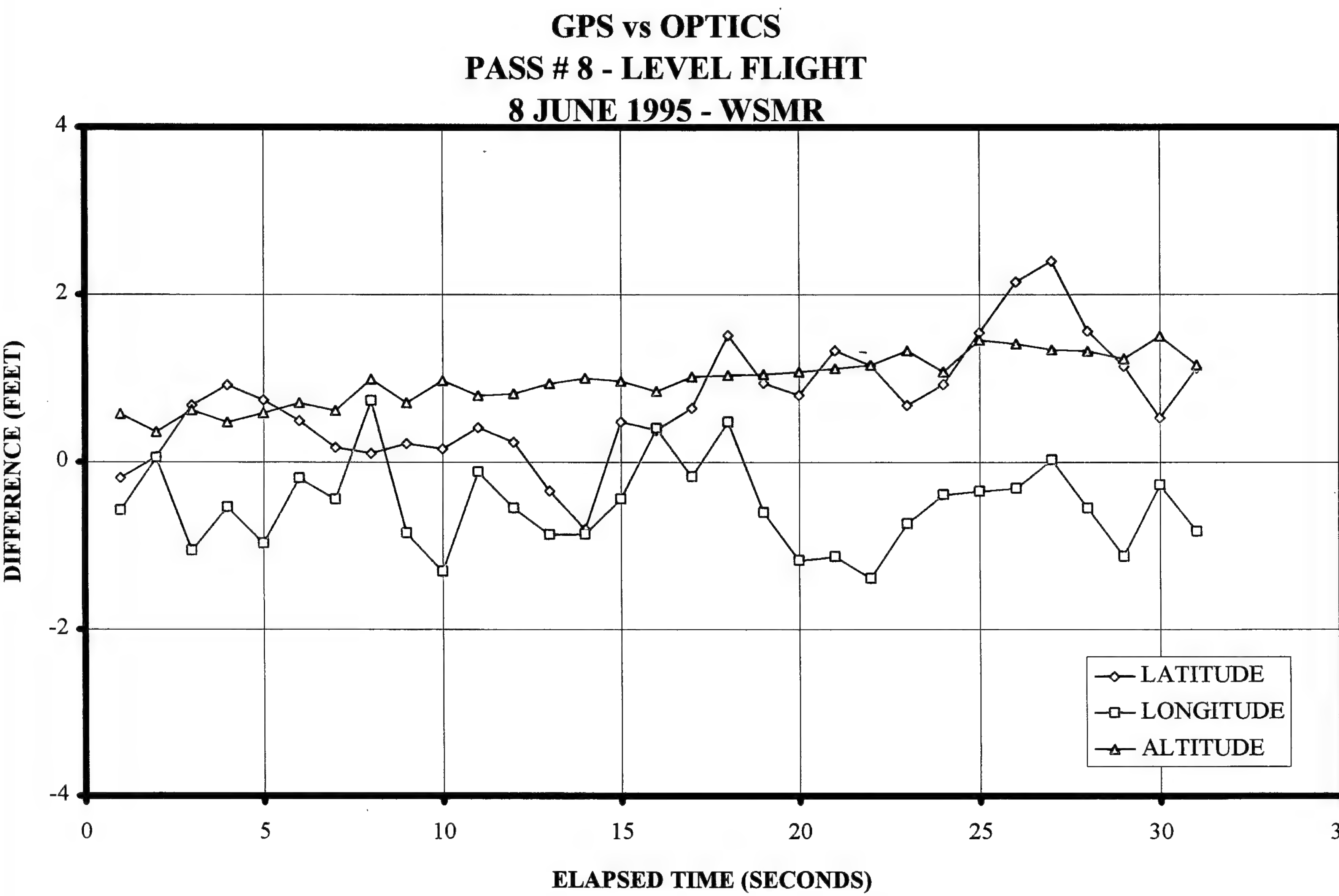
GPS vs OPTICS
PASS # 5 - 45 DEGREE BANK
8 JUNE 1995 - WSMR

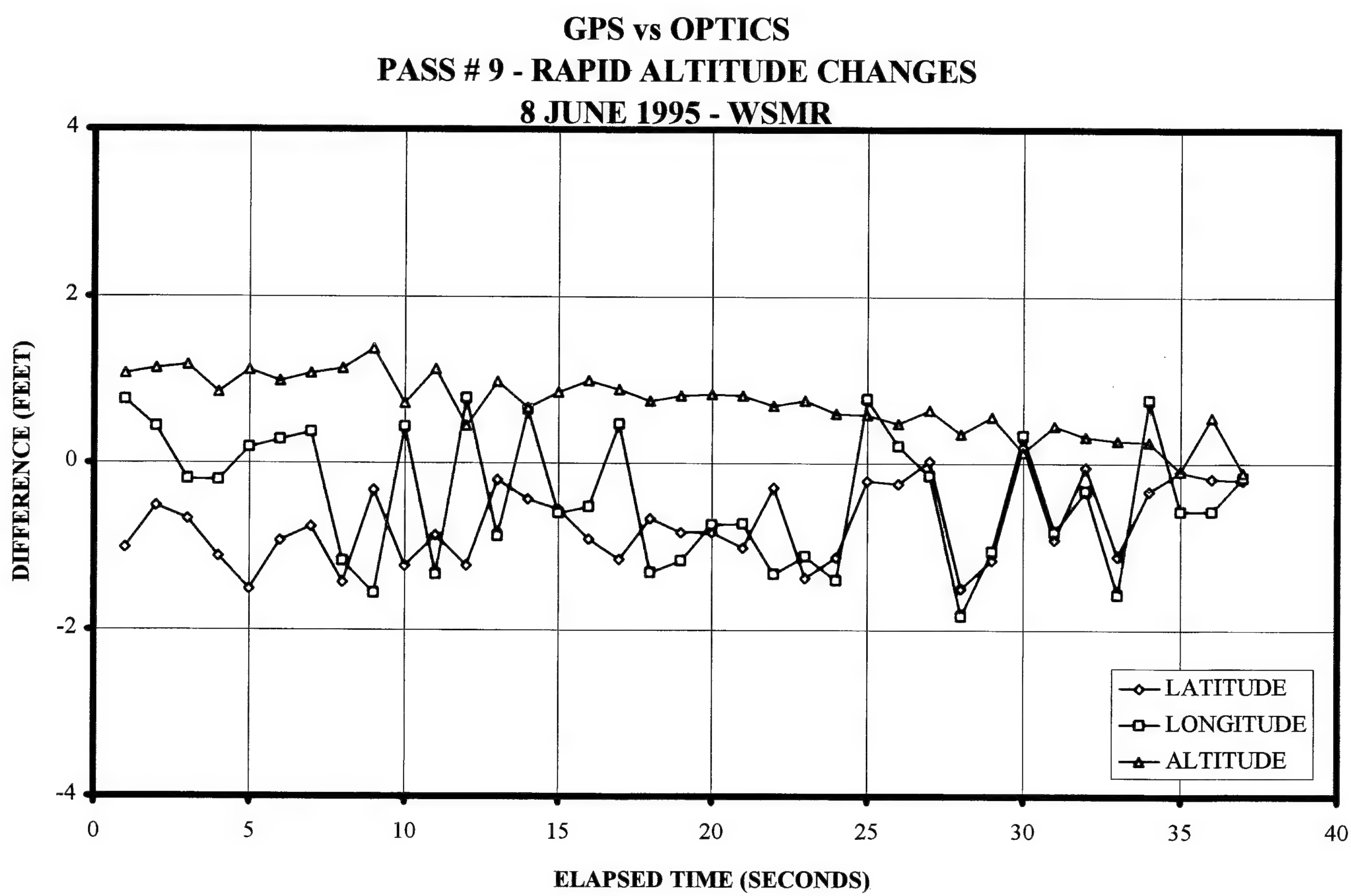



GPS vs OPTICS
PASS # 6 - 60 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
70
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

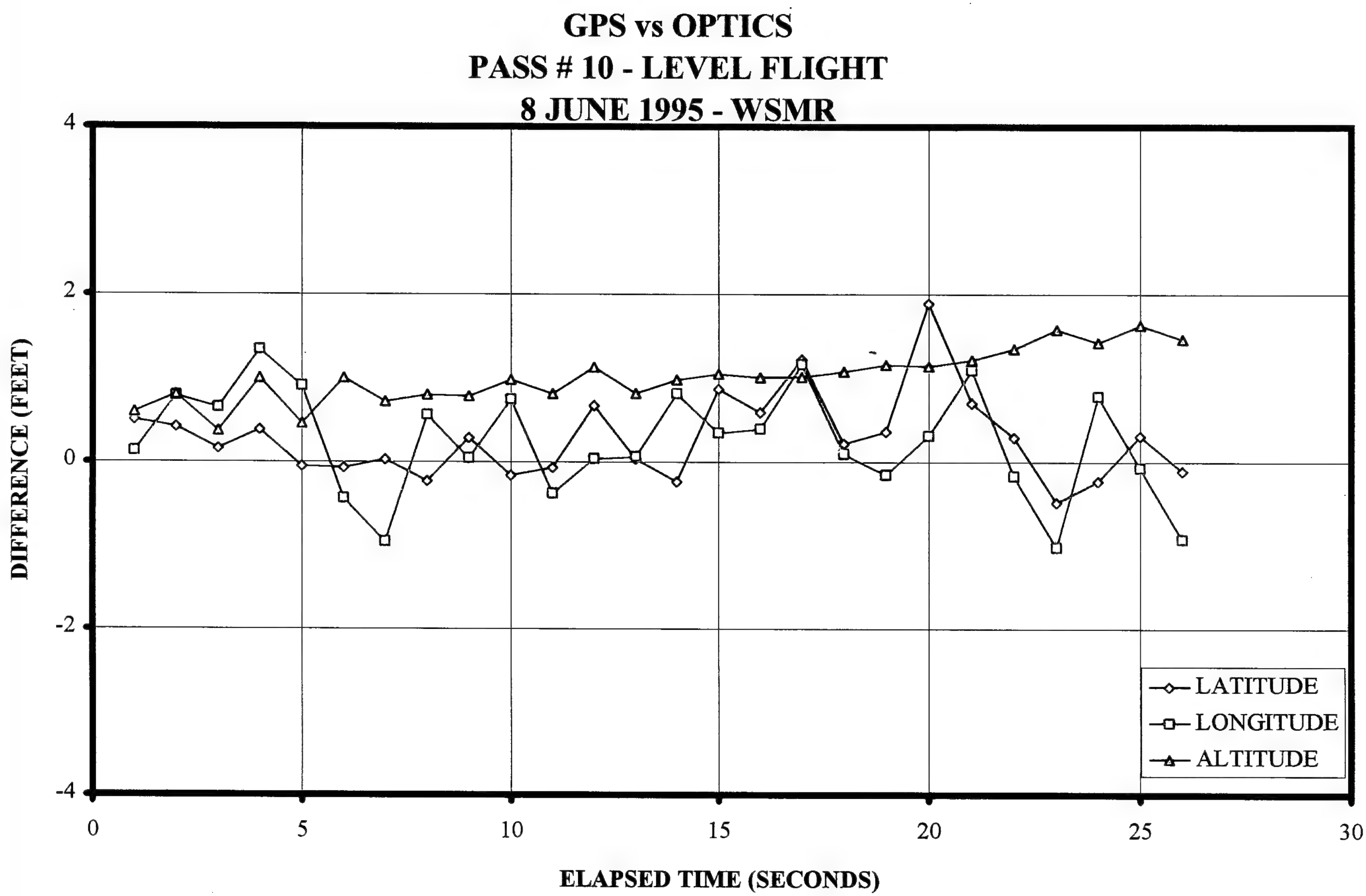
GPS vs OPTICS
PASS # 7 - FIGURE EIGHT
8 JUNE 1995 - WSMR

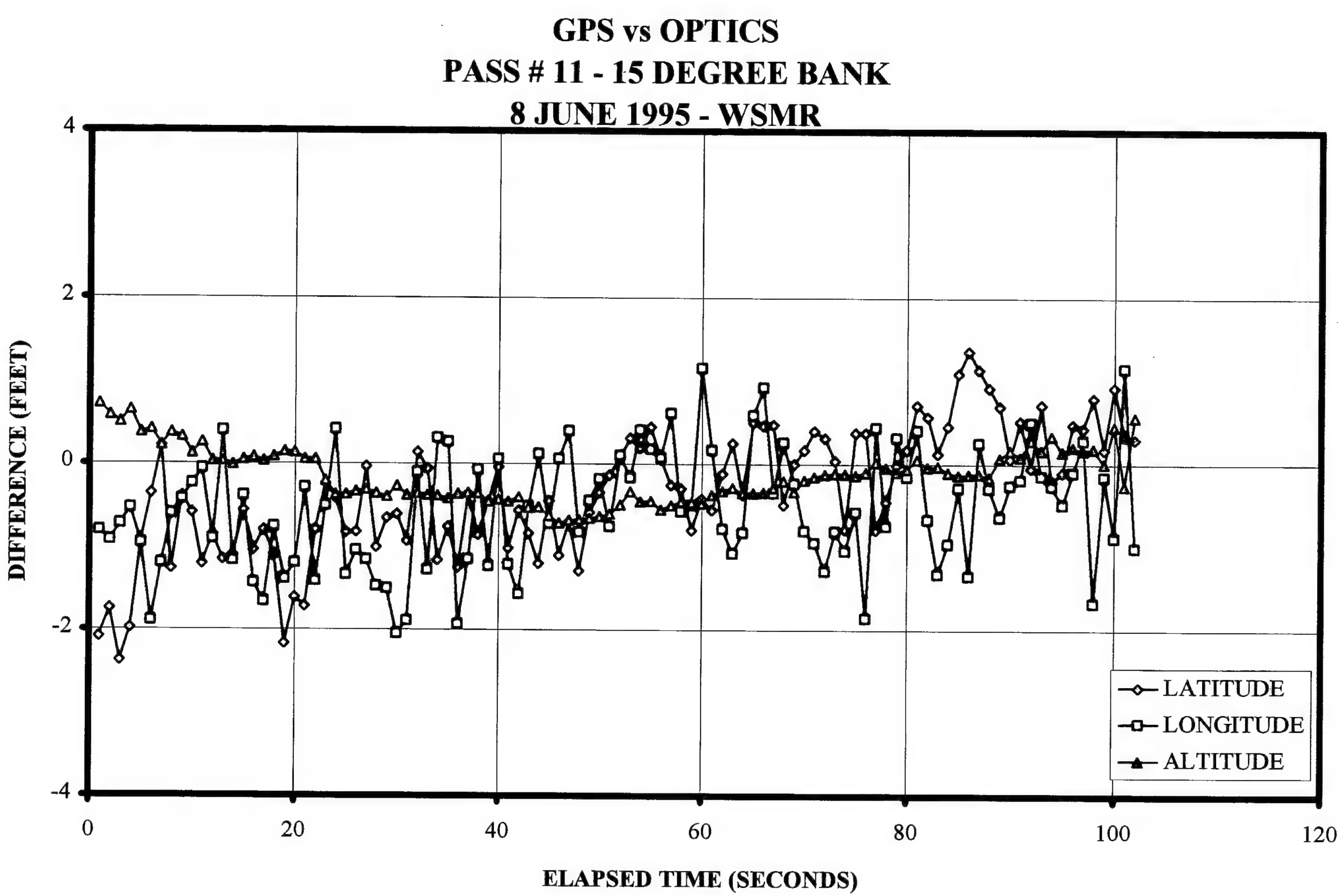


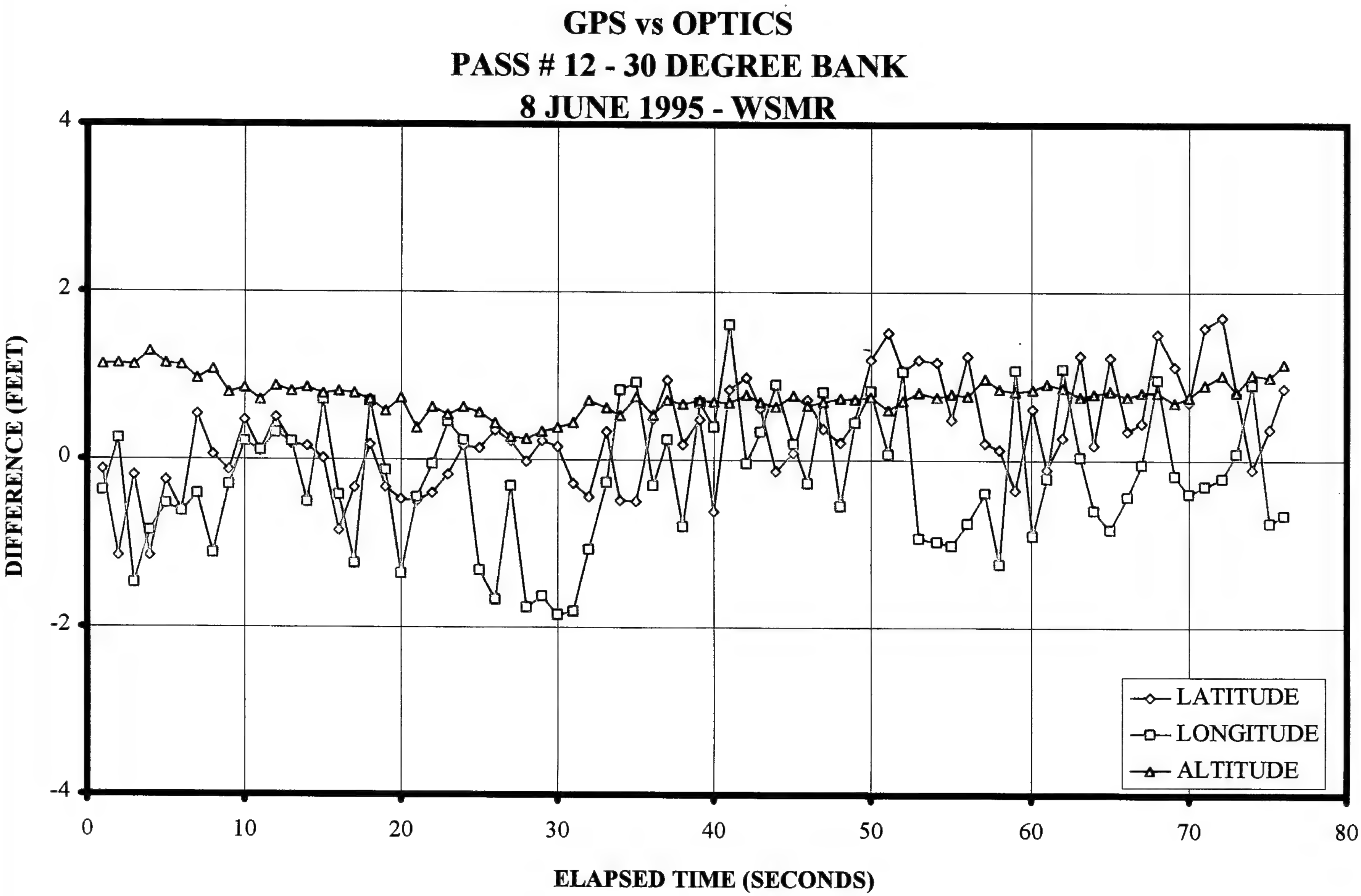

GPS vs OPTICS
PASS # 8 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
35
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

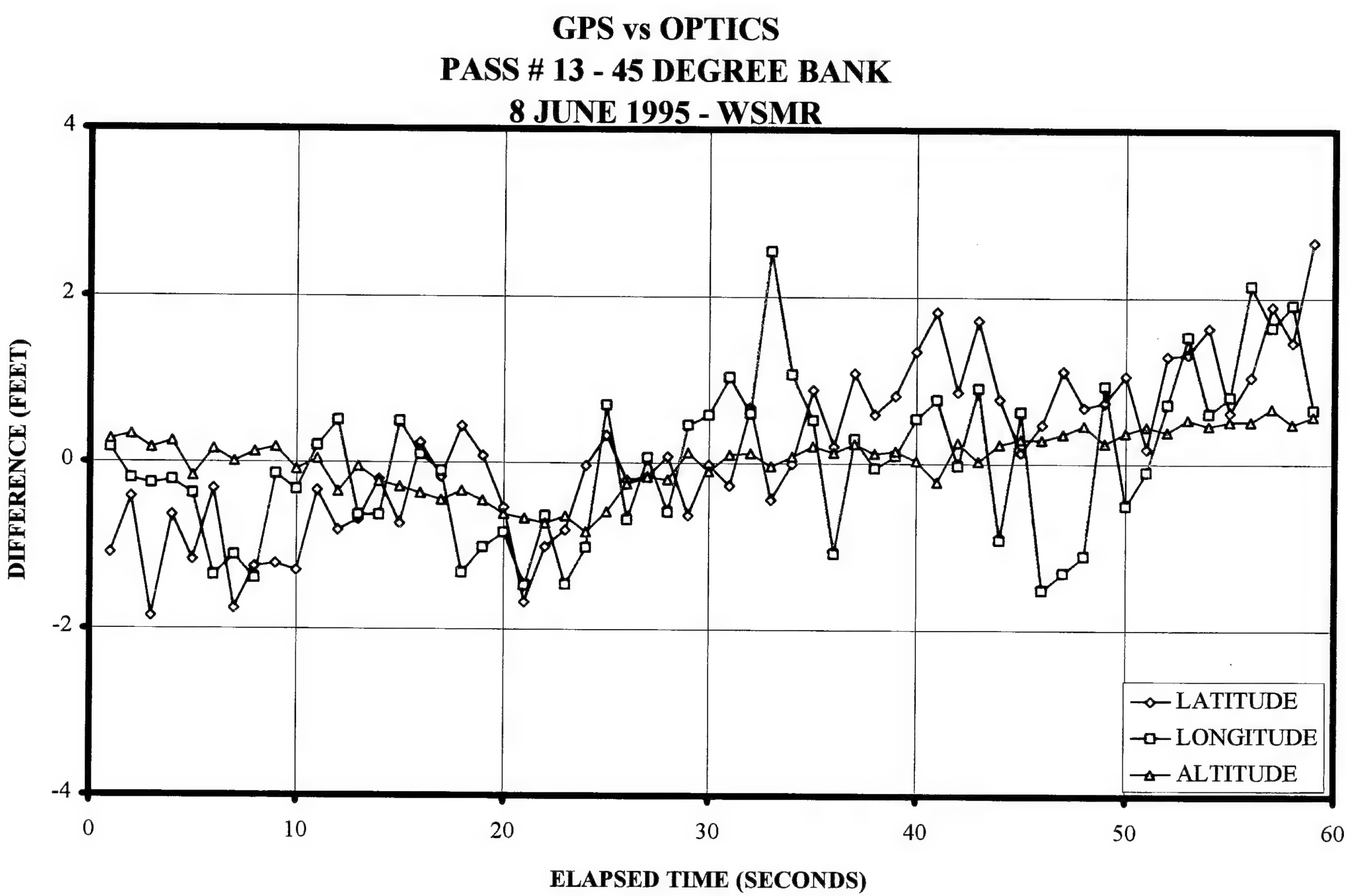


GPS vs OPTICS
PASS # 9 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
35
40
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

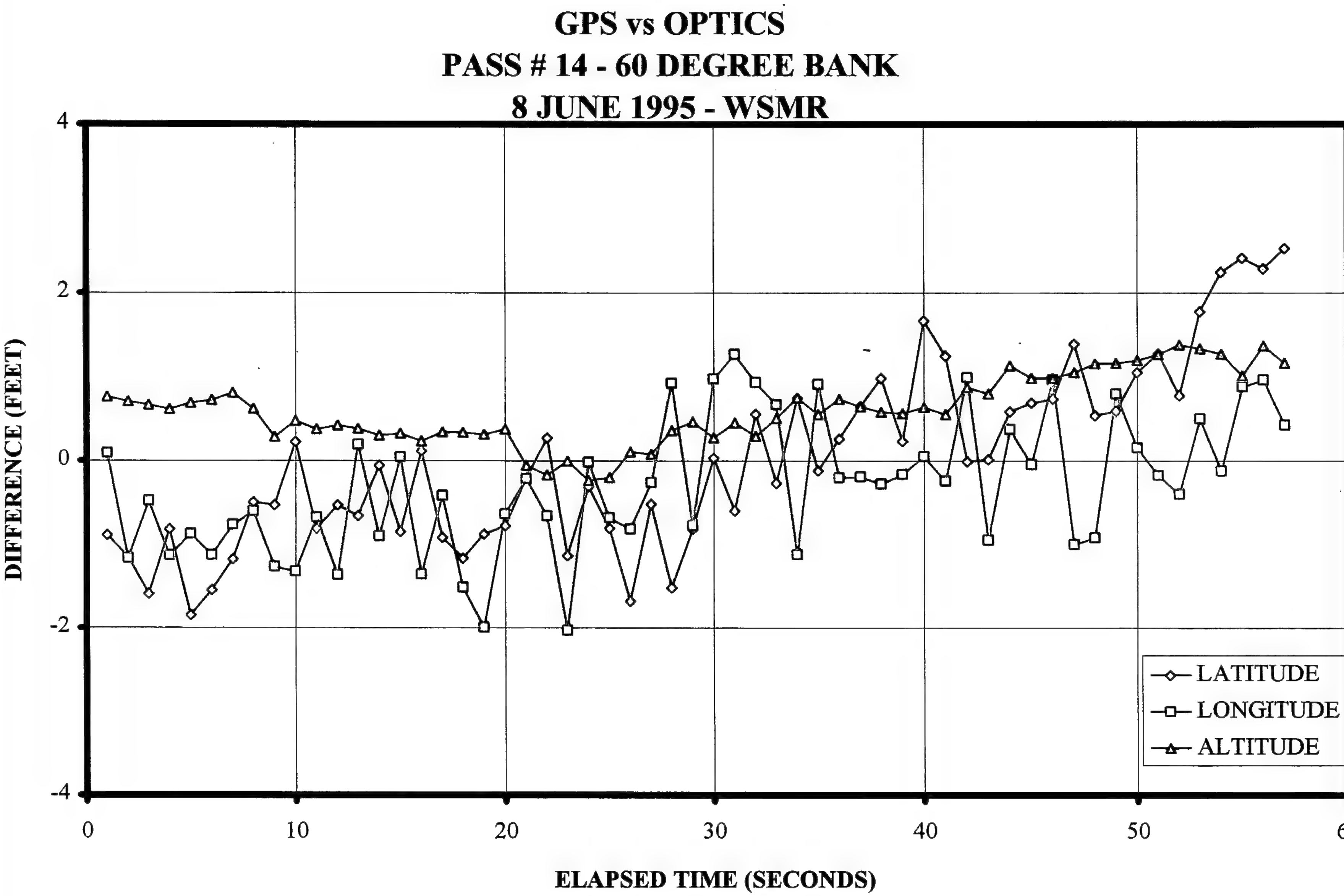

GPS vs OPTICS
PASS # 10 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE


GPS vs OPTICS
PASS # 11 - 15 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
20
40
60
80
100
120
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

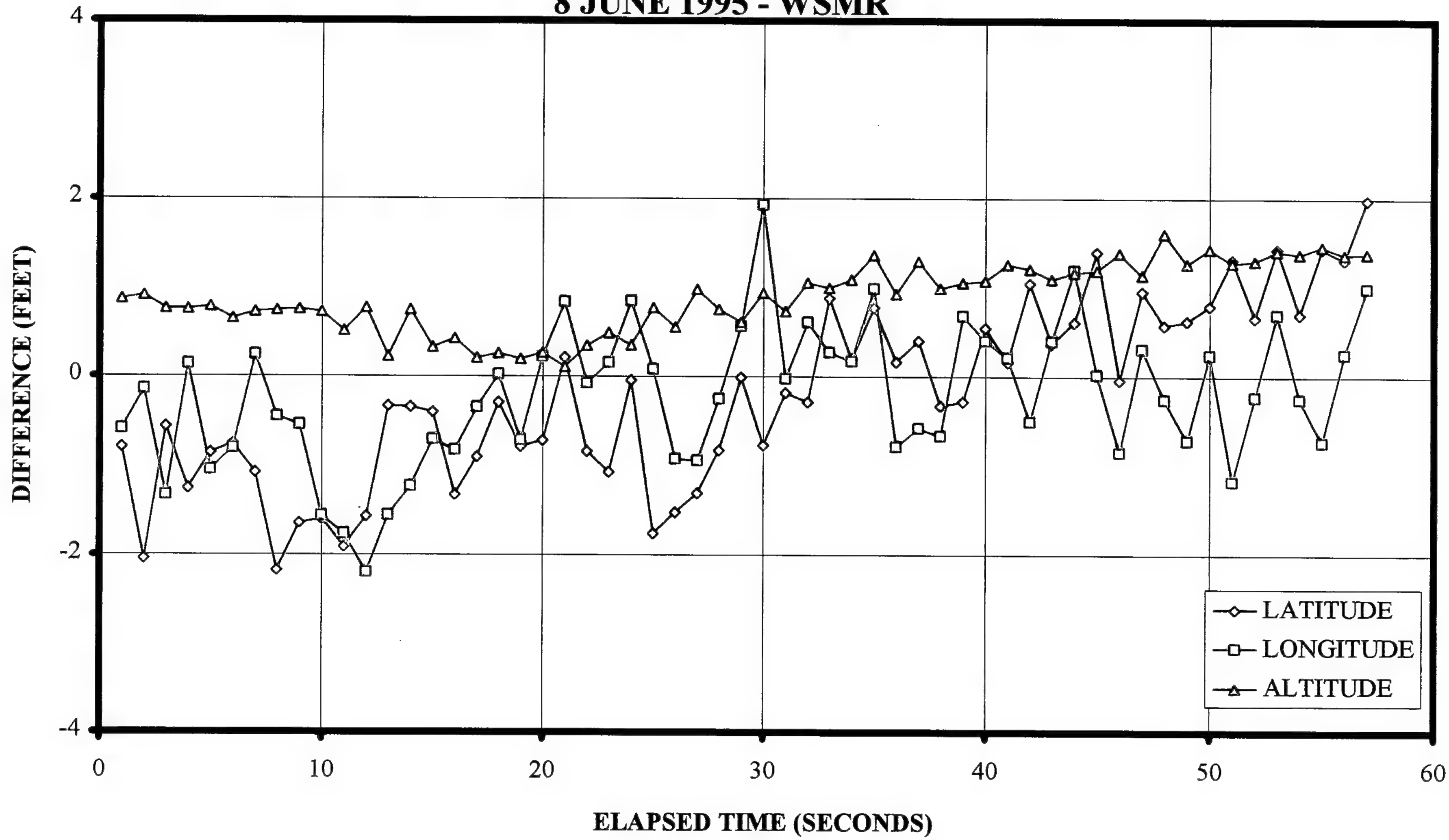

GPS vs OPTICS
PASS # 12 - 30 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE



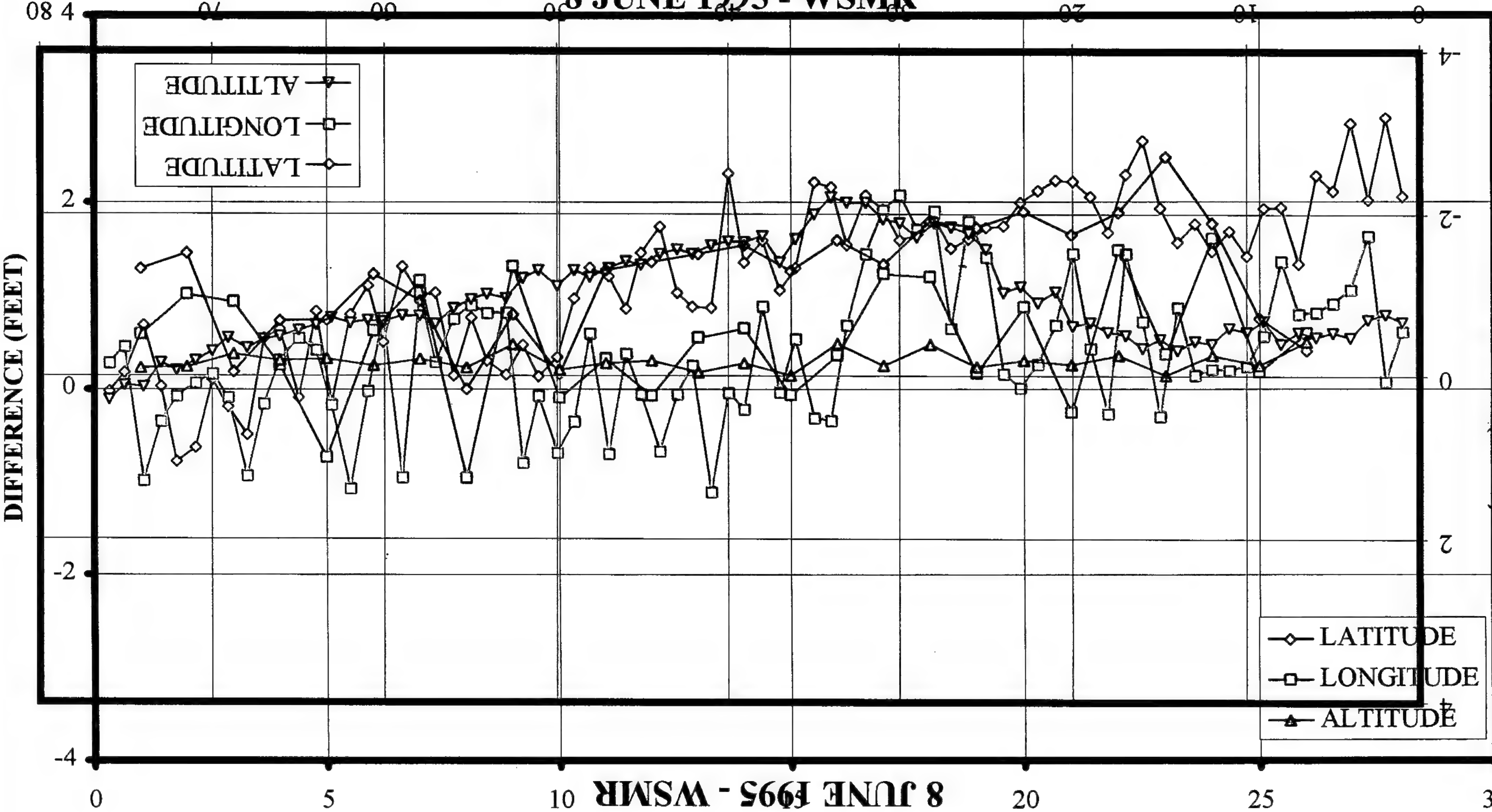
GPS vs OPTICS
PASS # 13 - 45 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE


GPS vs OPTICS
PASS # 14 - 60 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

GPS vs OPTICS
PASS # 15 - FIGURE EIGHT
8 JUNE 1995 - WSMR

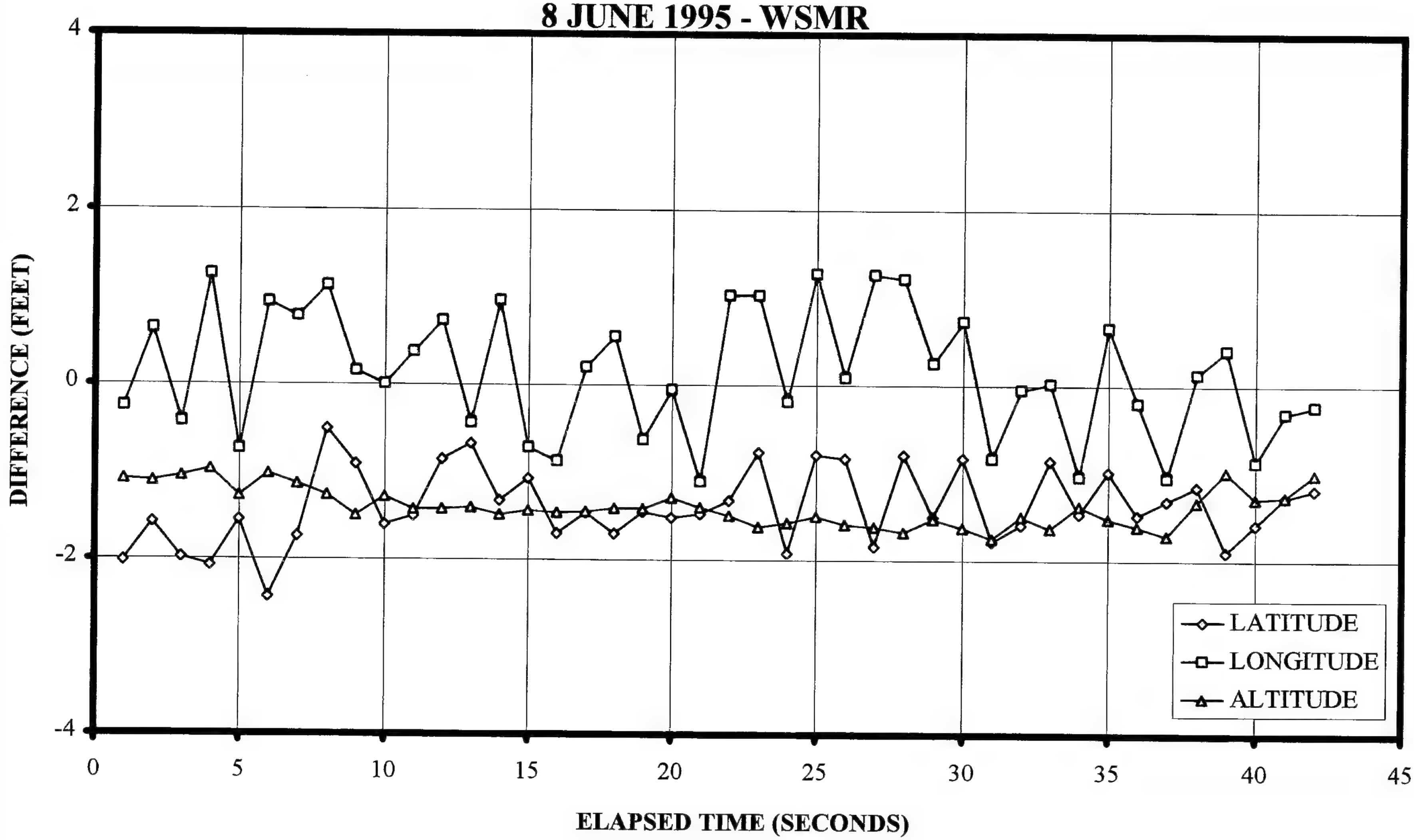


GPS vs OPTICS
PASS # 16 - LEVEL FLIGHT
8 JUNE 1995 - WSMR

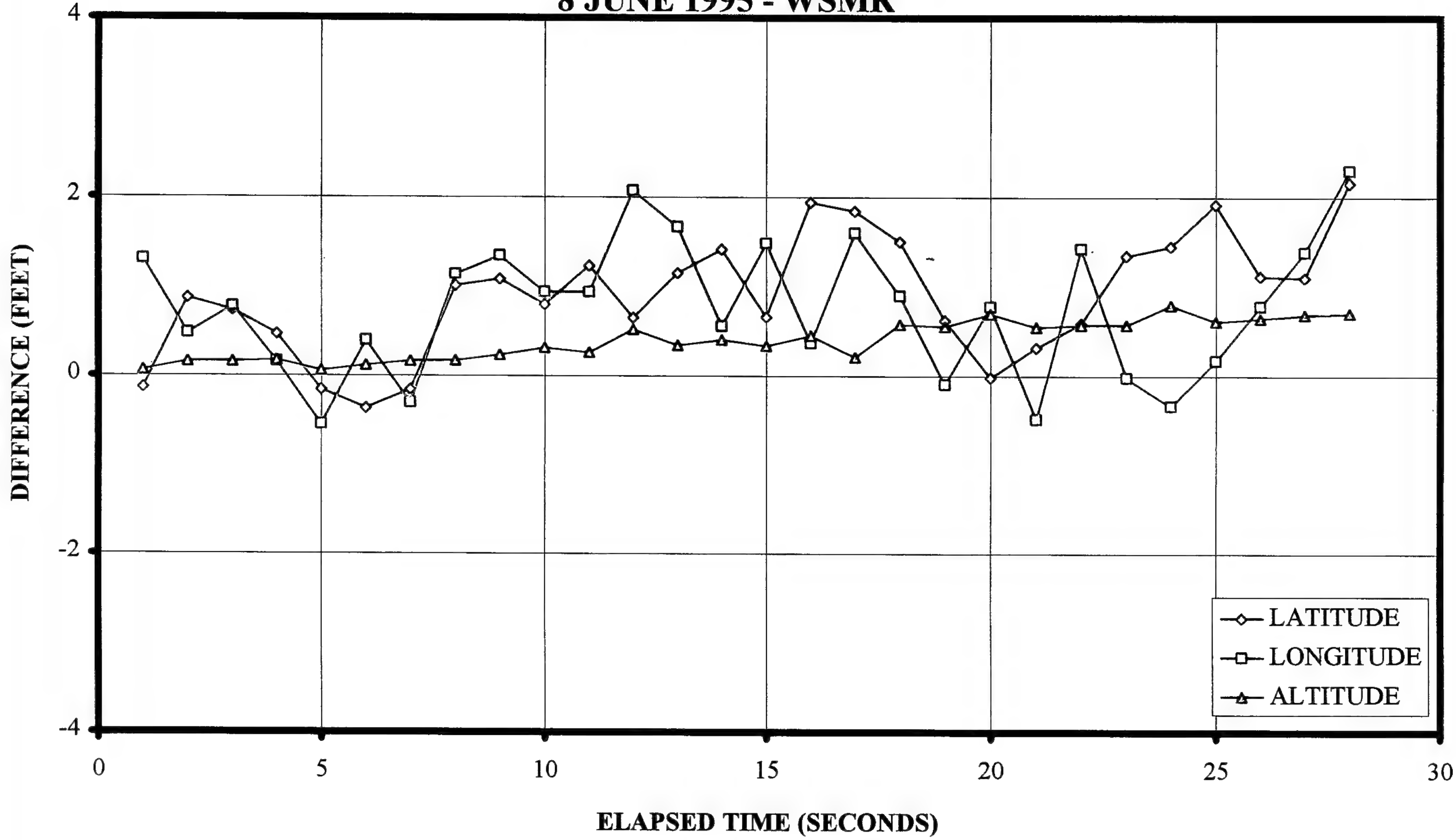


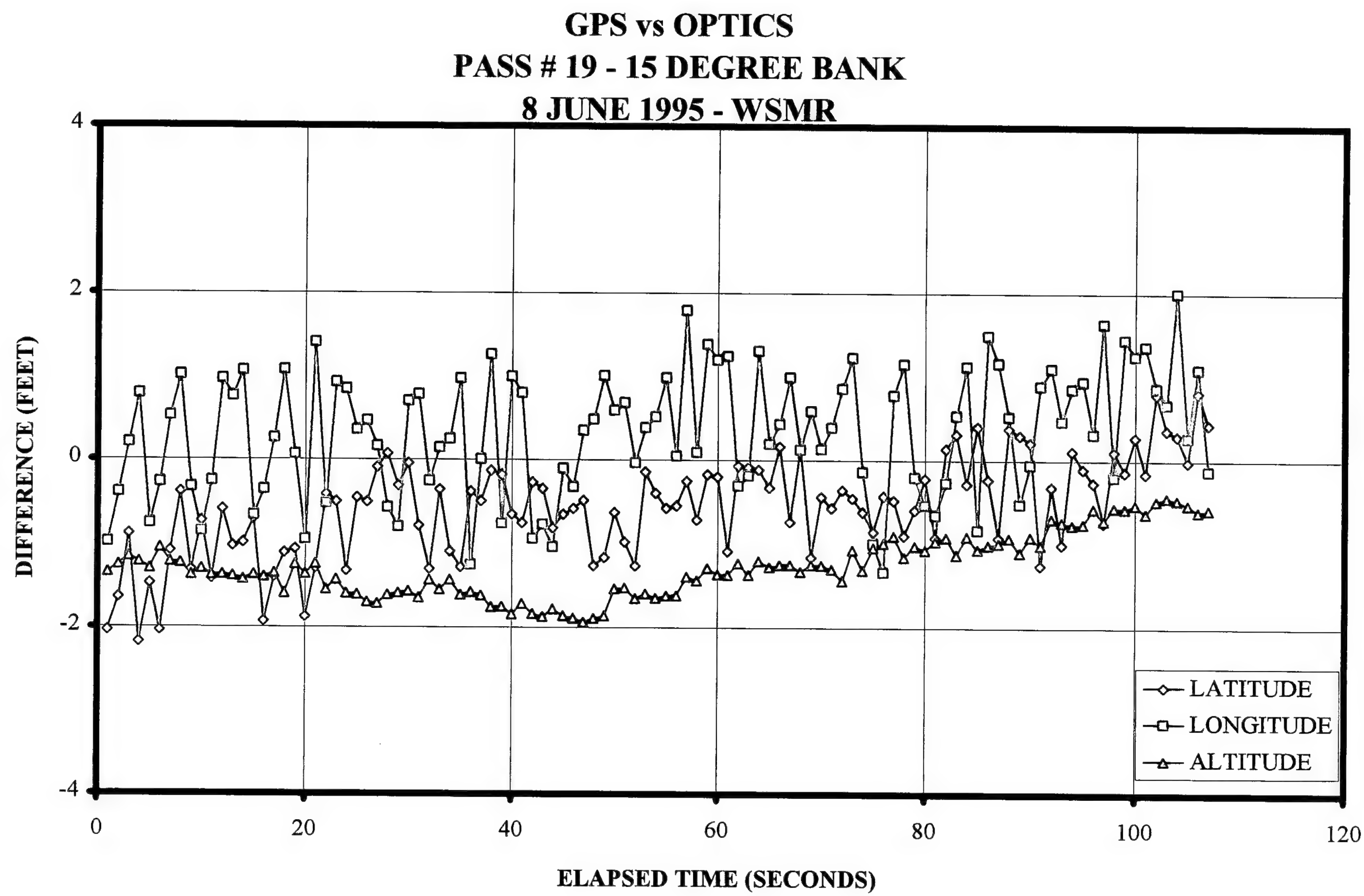
ELAPSED TIME (SECONDS)

GPS vs OPTICS
PASS # 17 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR



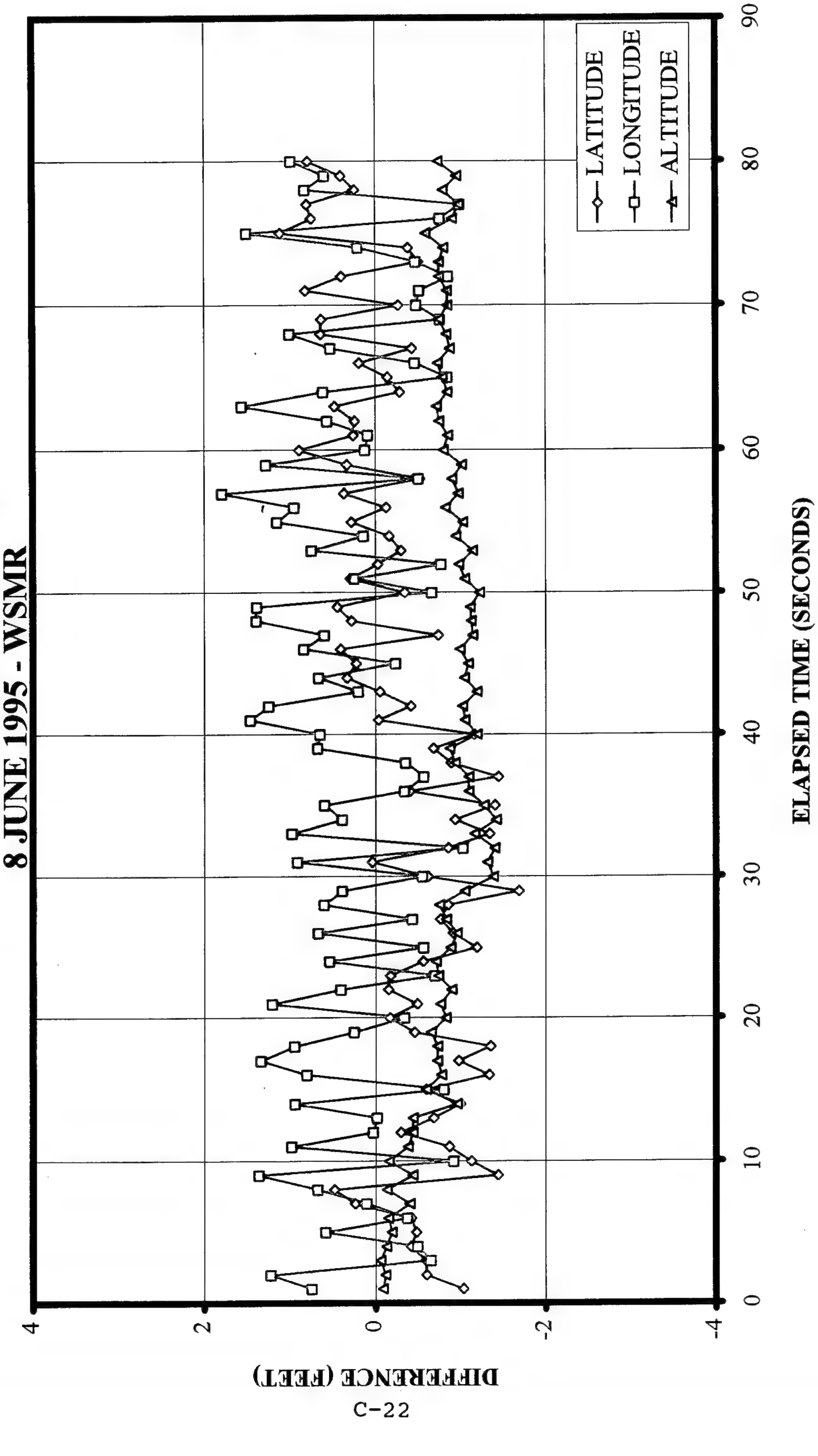
GPS vs OPTICS
PASS # 18 - LEVEL FLIGHT
8 JUNE 1995 - WSMR





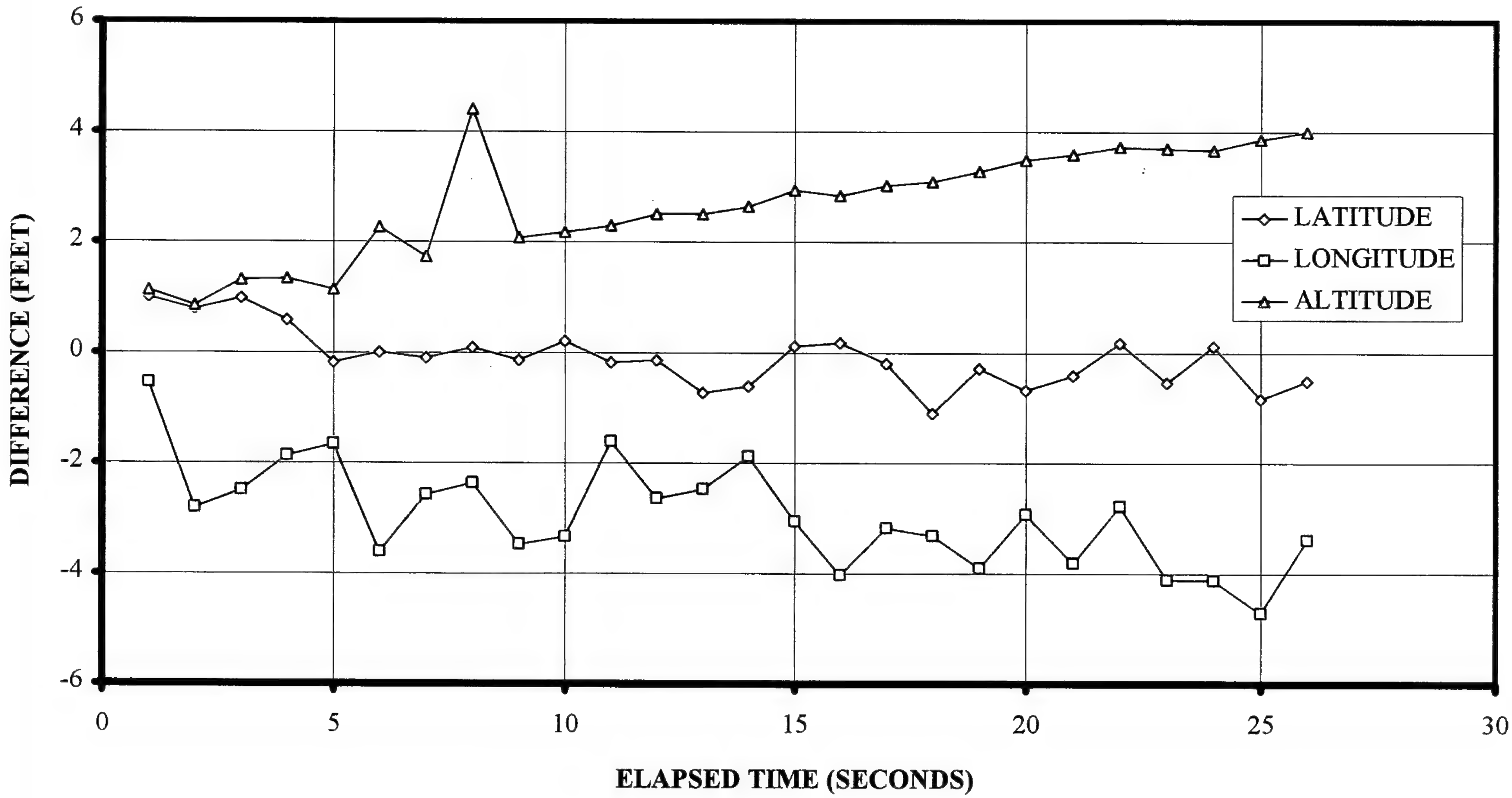
GPS vs OPTICS
PASS # 19 - 15 DEGREE BANK
8 JUNE 1995 - WSMR
4
2
0
-2
-4
DIFFERENCE (FEET)
0
20
40
60
80
100
120
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

GPS vs OPTICS
PASS # 20 - 30 DEGREE BANK
8 JUNE 1995 - WSMR

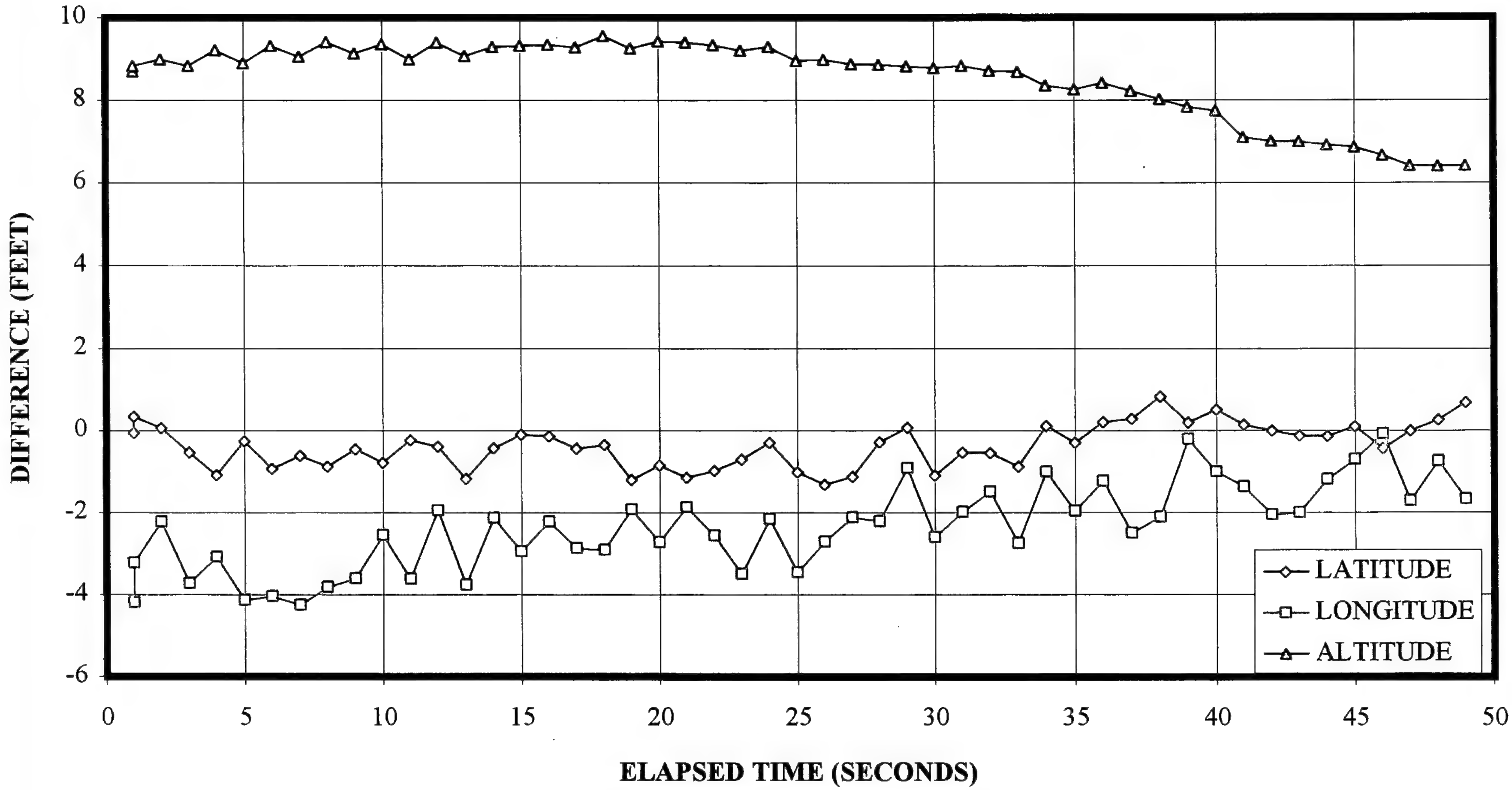


APPENDIX D. COMPARISON OF REAL-TIME GPS POSITION SOLUTION TO WSMR OPTICS DATA

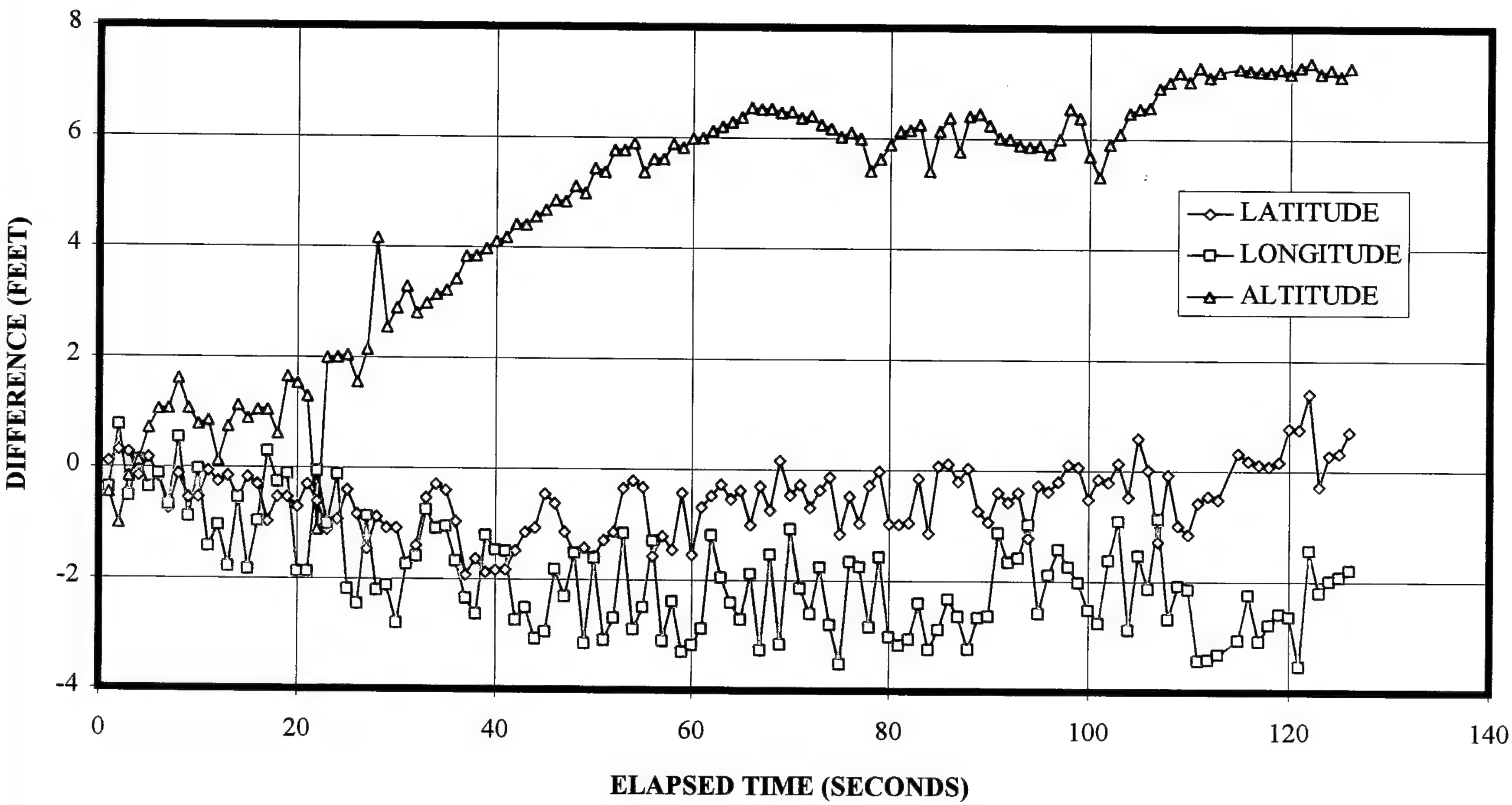
REAL-TIME GPS vs OPTICS
PASS # 1 - LEVEL FLIGHT
8 JUNE 1995 - WSMR



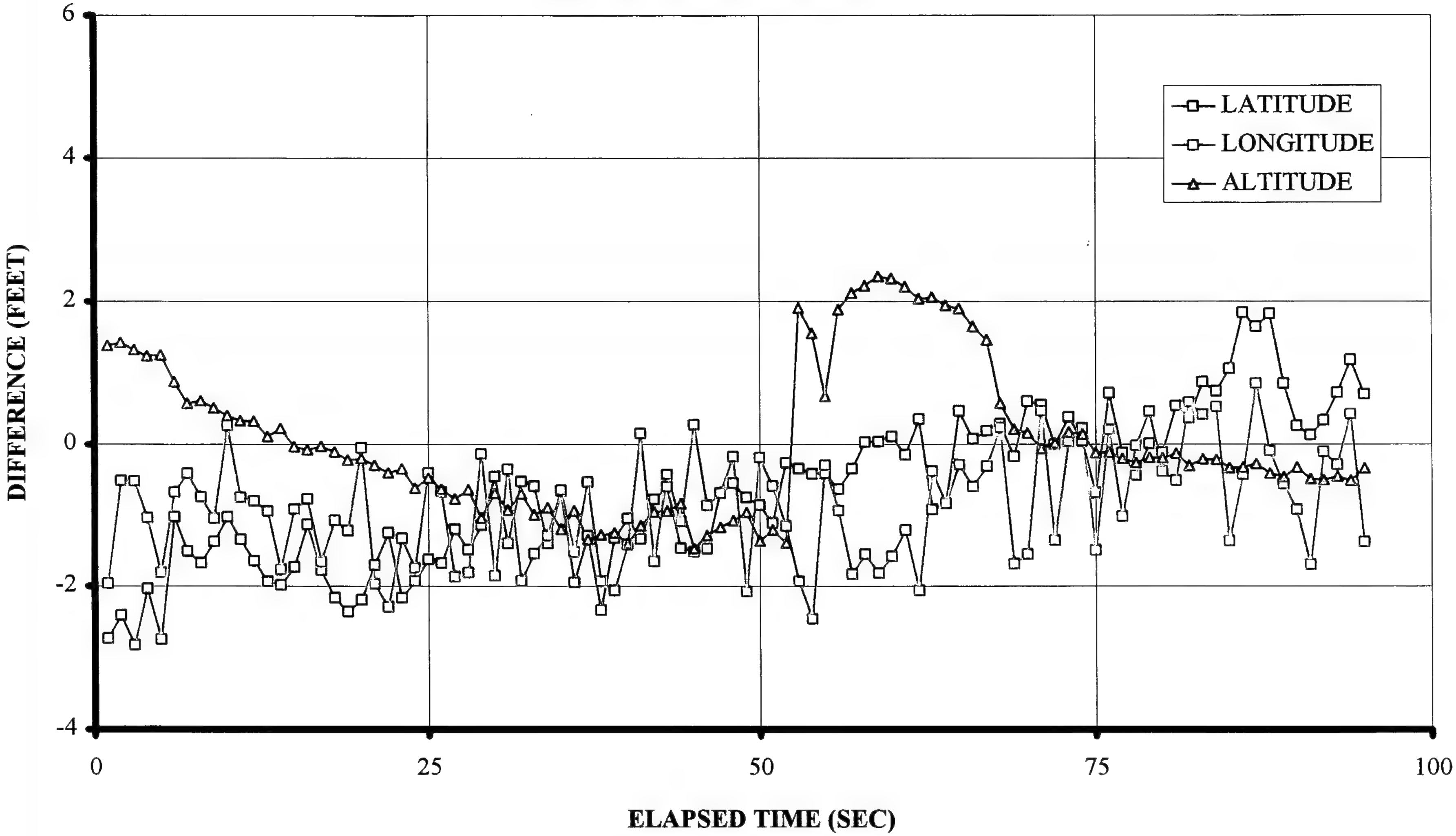
REAL-TIME GPS vs OPTICS
PASS # 2 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR



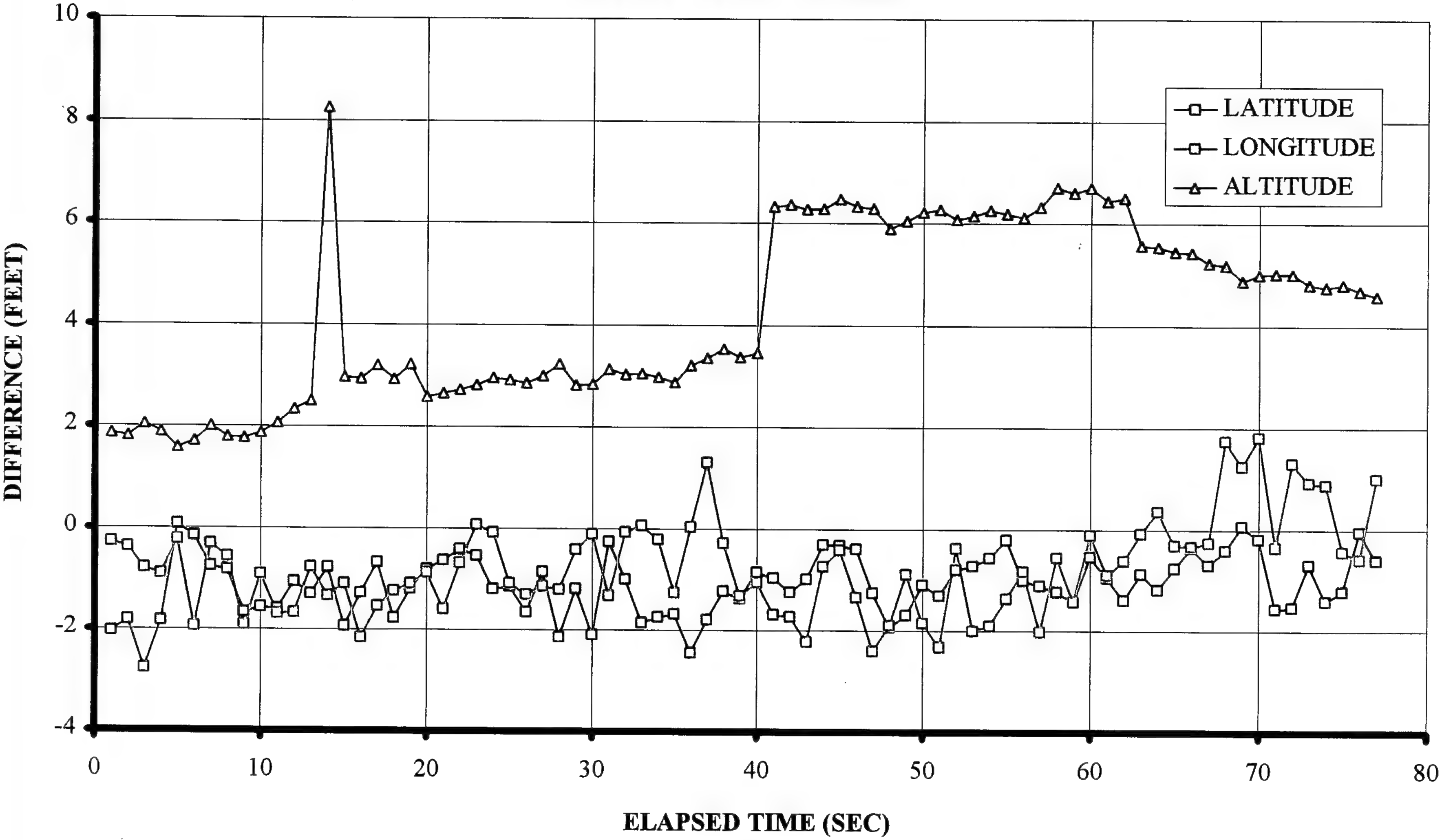
REAL-TIME GPS vs OPTICS
PASS # 3 - 15 DEGREE BANK
8 JUNE 1995 - WSMR



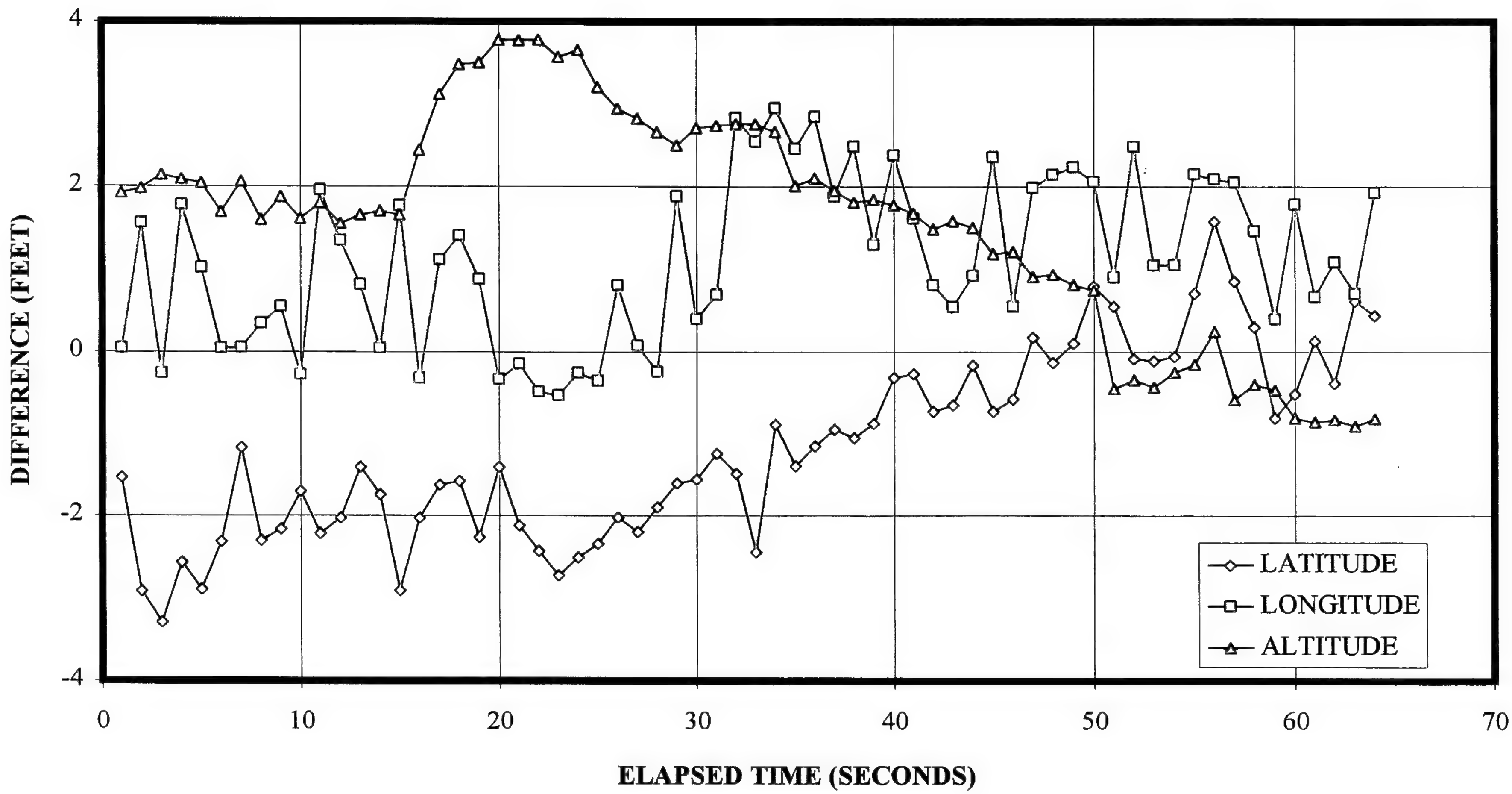
REAL-TIME GPS vs OPTICS
PASS # 4 - 30 DEGREE BANK
8 JUNE 1995 - WSMR



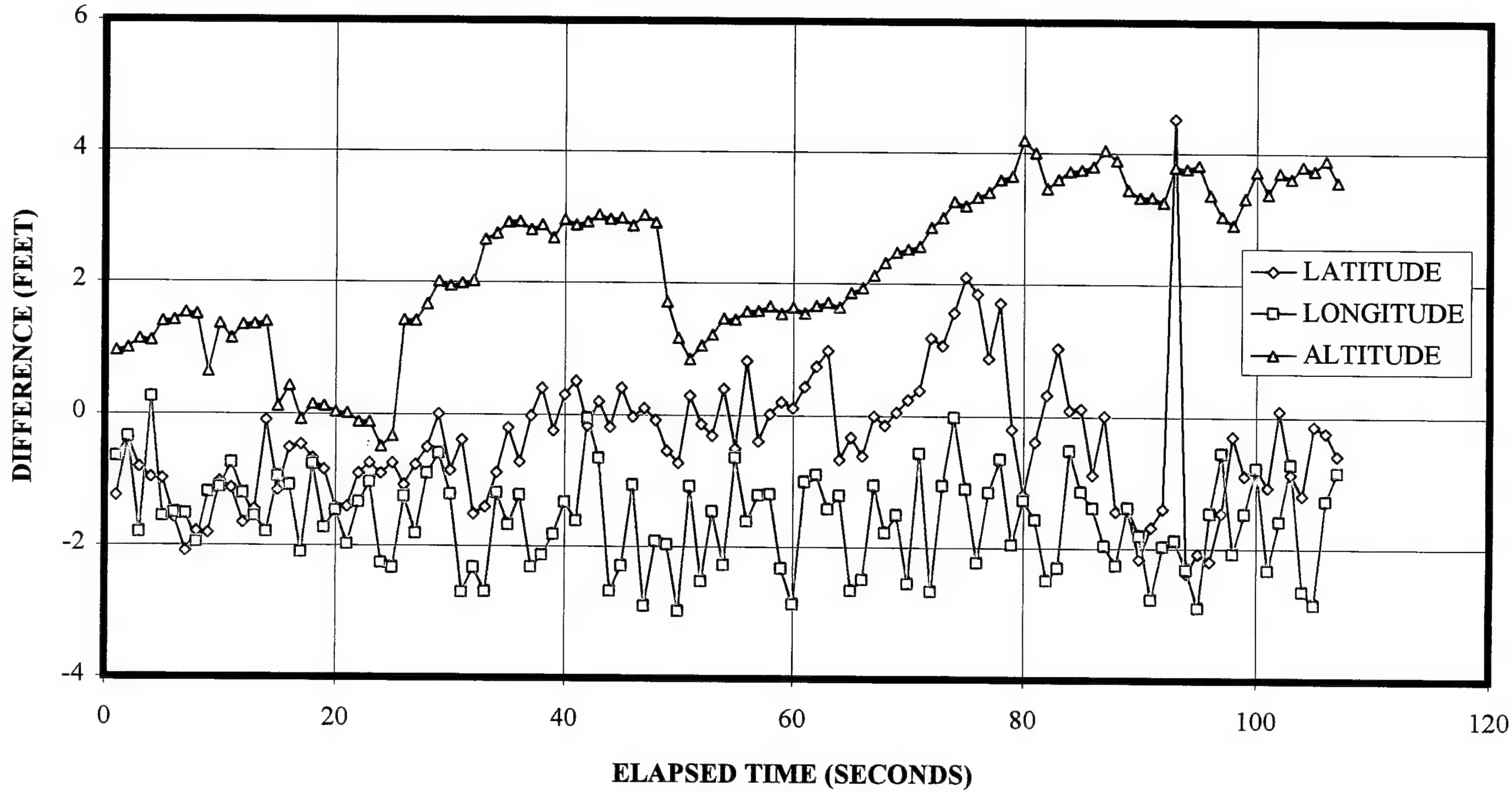
REAL-TIME GPS vs OPTICS
PASS # 5 - 45 DEGREE BANK
8 JUNE 1995 - WSMR



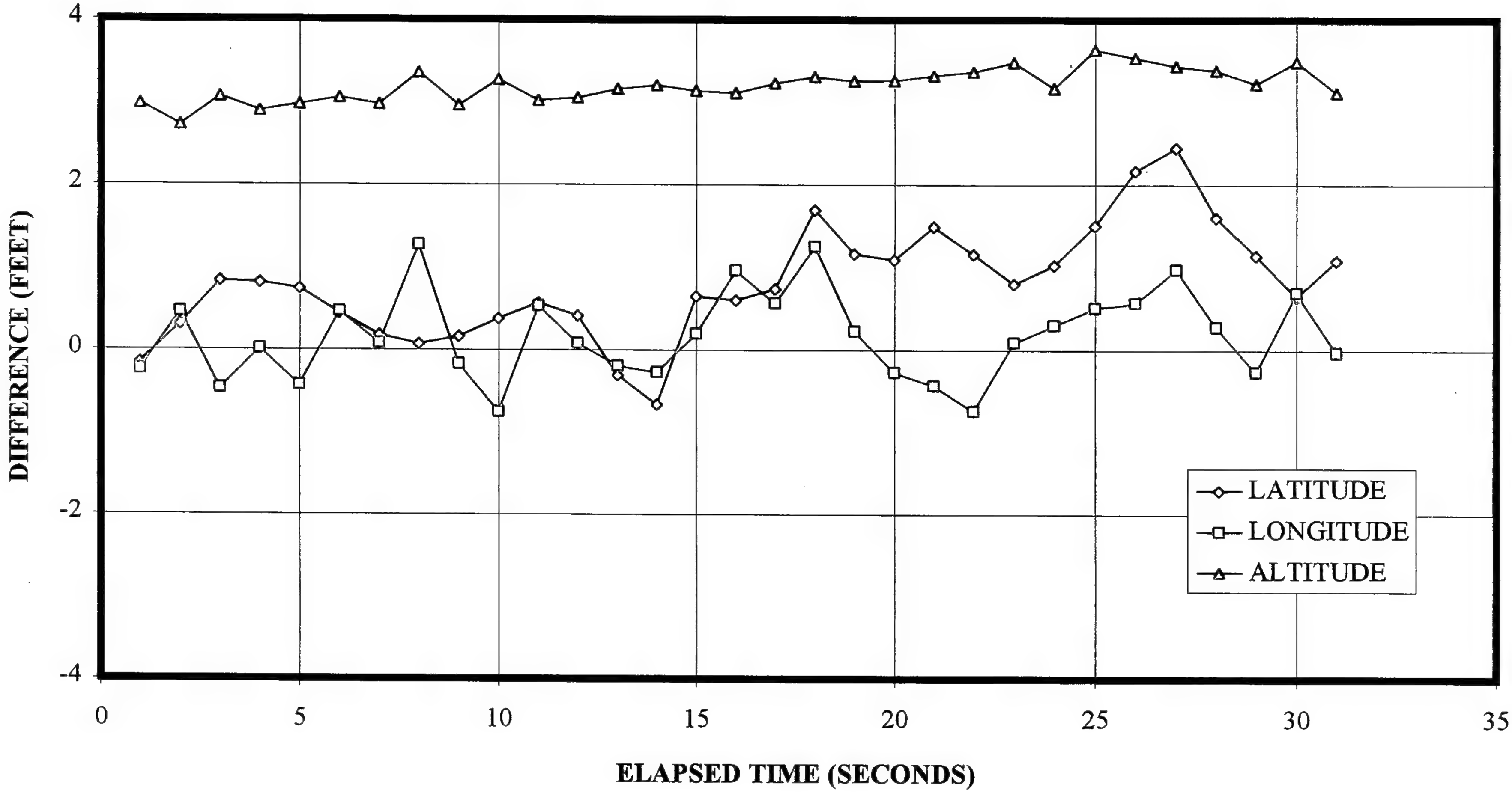
REAL-TIME GPS vs OPTICS
PASS # 6 - 60 DEGREE BANK
8 JUNE 1995 - WSMR



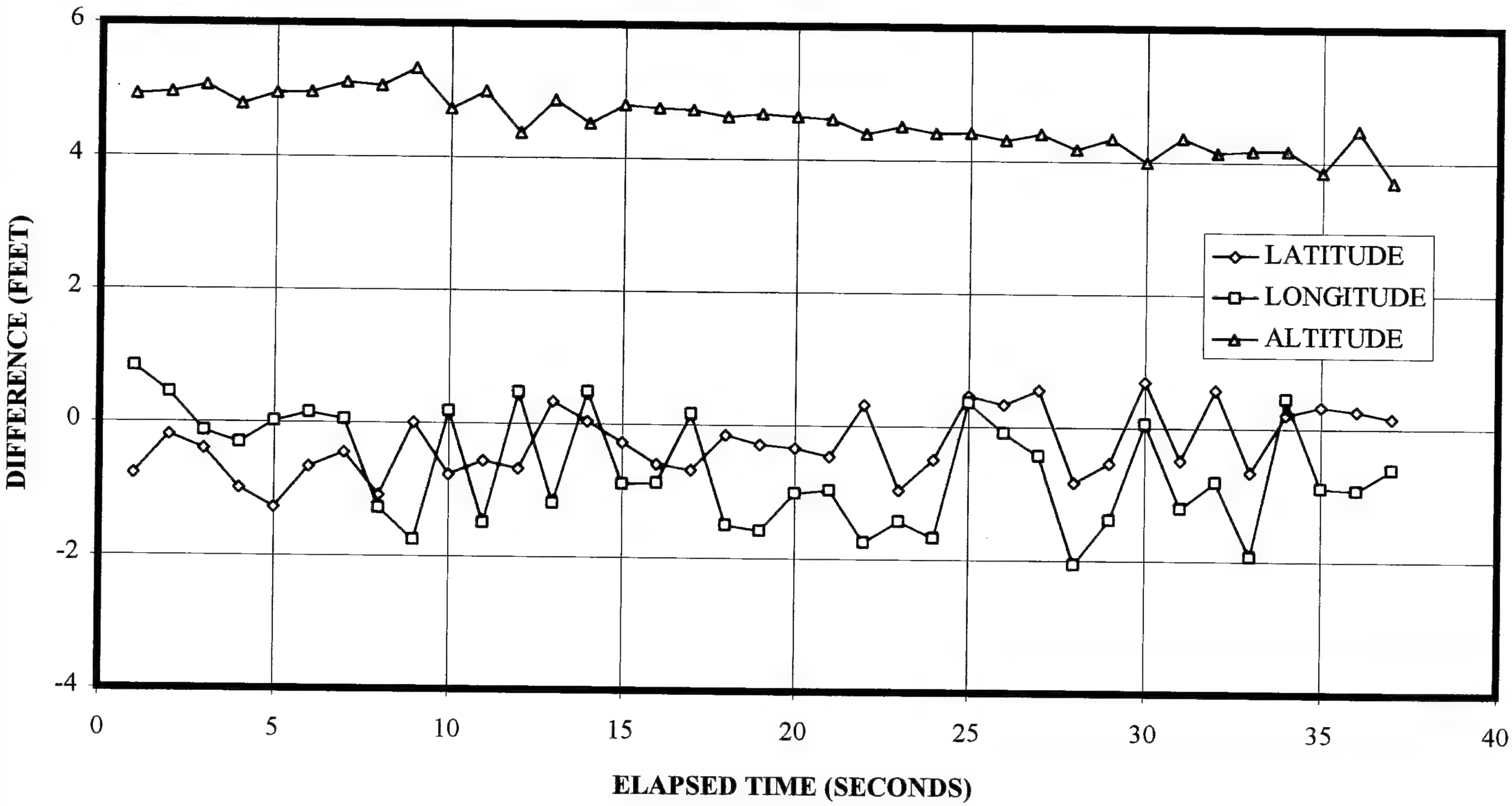
REAL-TIME GPS vs OPTICS
PASS # 7 - FIGURE EIGHT
8 JUNE 1995 - WSMR



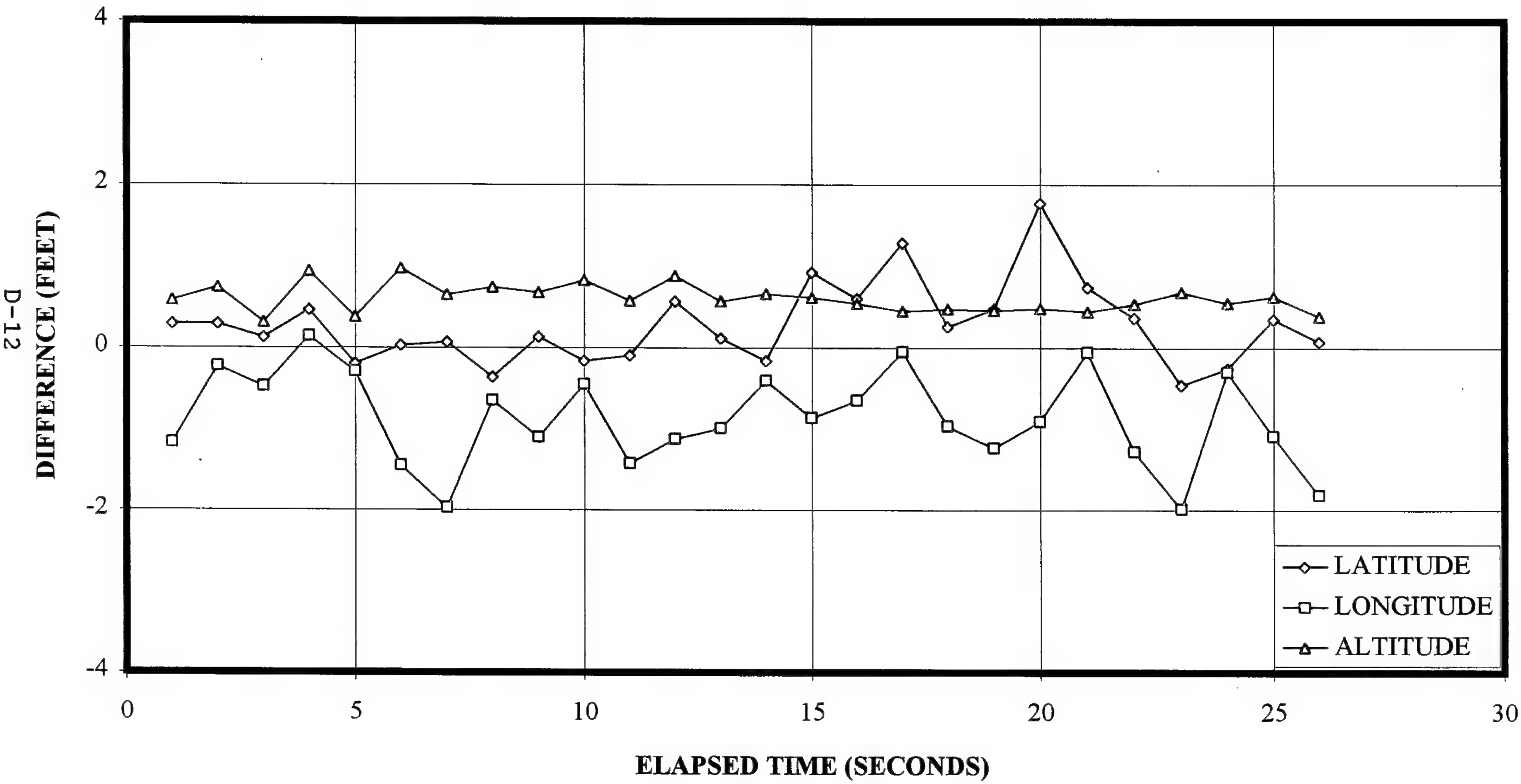
REAL-TIME GPS vs OPTICS
PASS # 8 - LEVEL FLIGHT
8 JUNE 1995 - WSMR



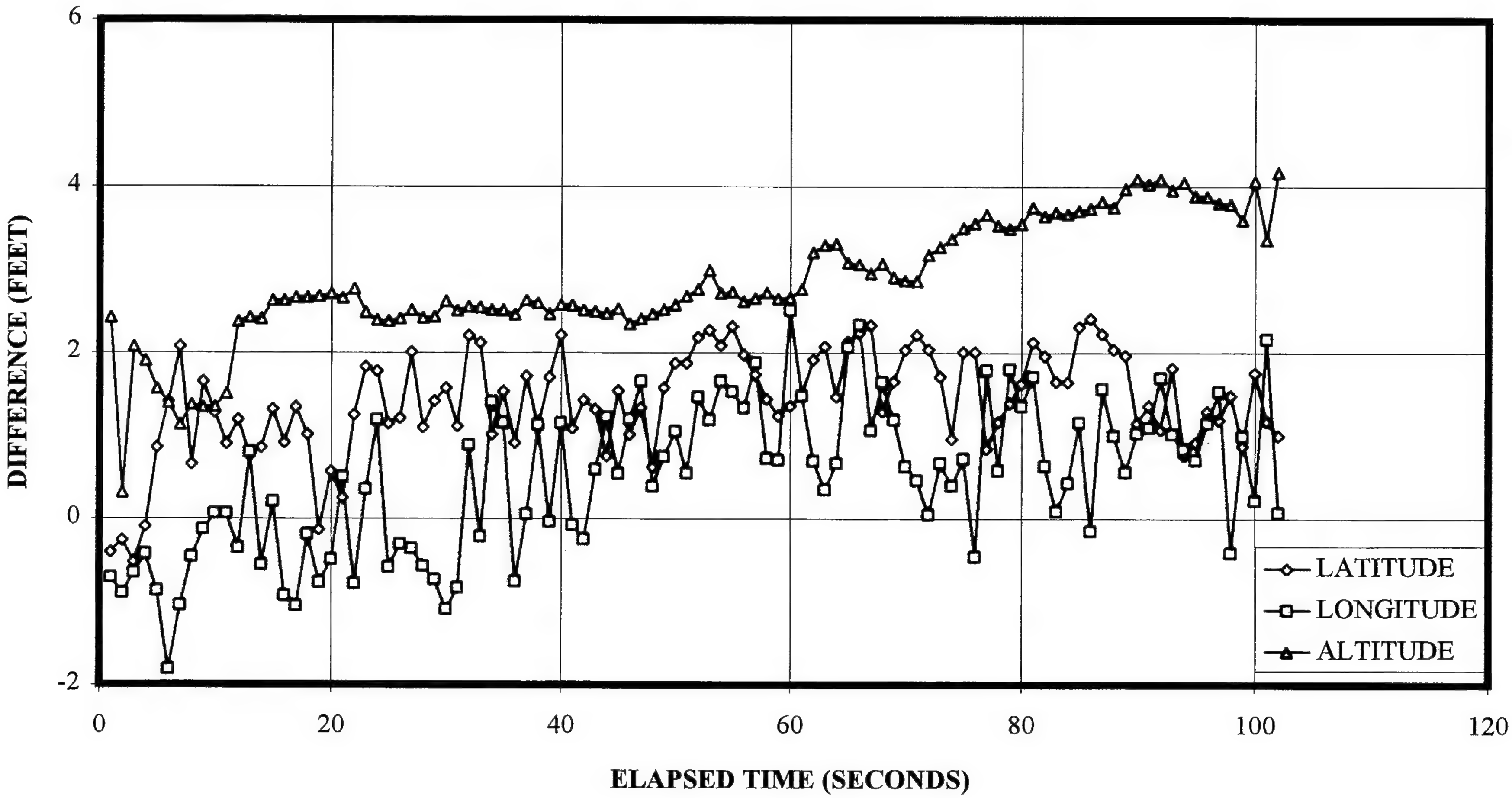
REAL-TIME GPS vs OPTICS
PASS # 9 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR



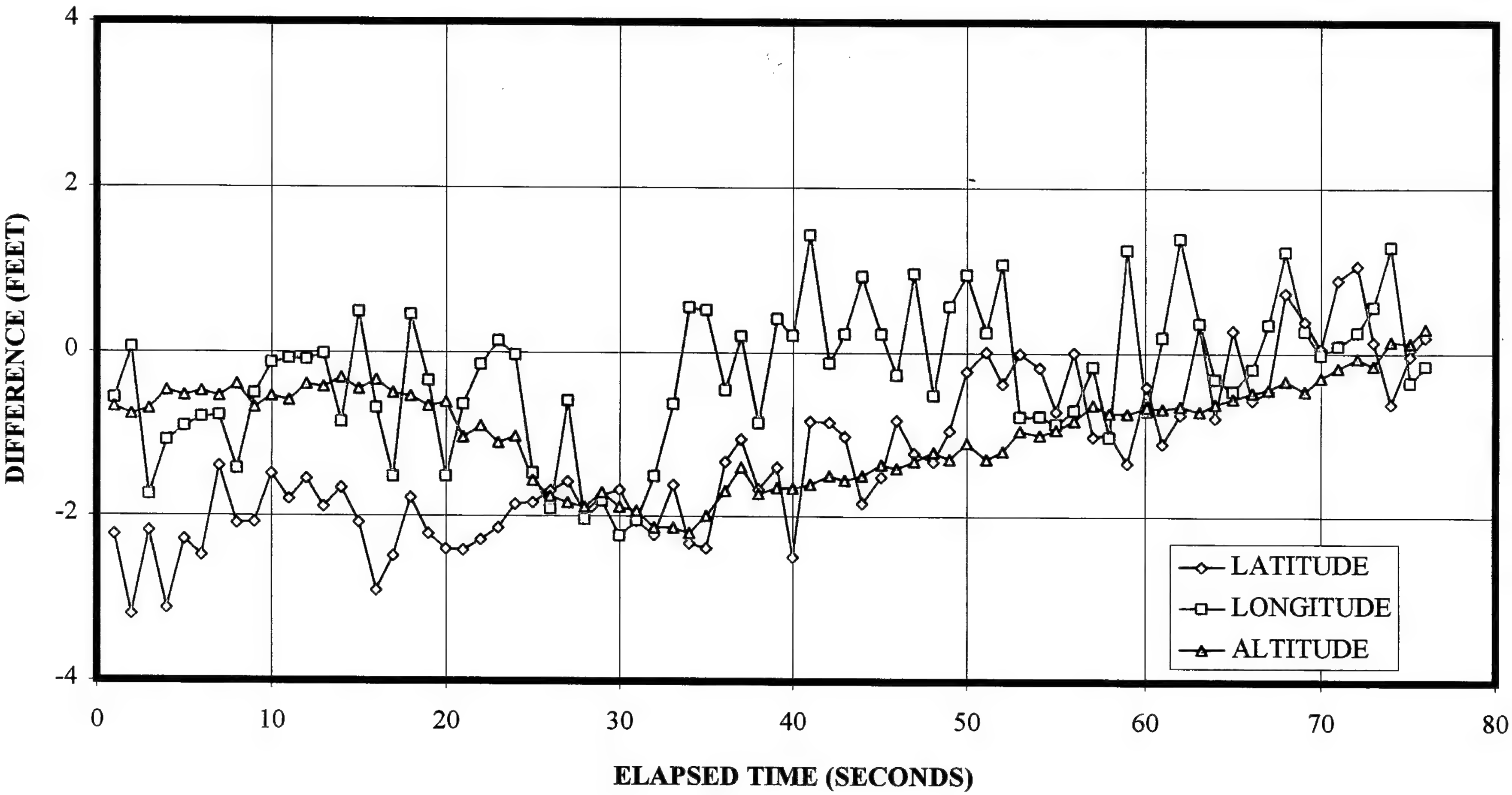
REAL-TIME GPS vs OPTICS
PASS # 10 - LEVEL FLIGHT
8 JUNE 1995 - WSMR



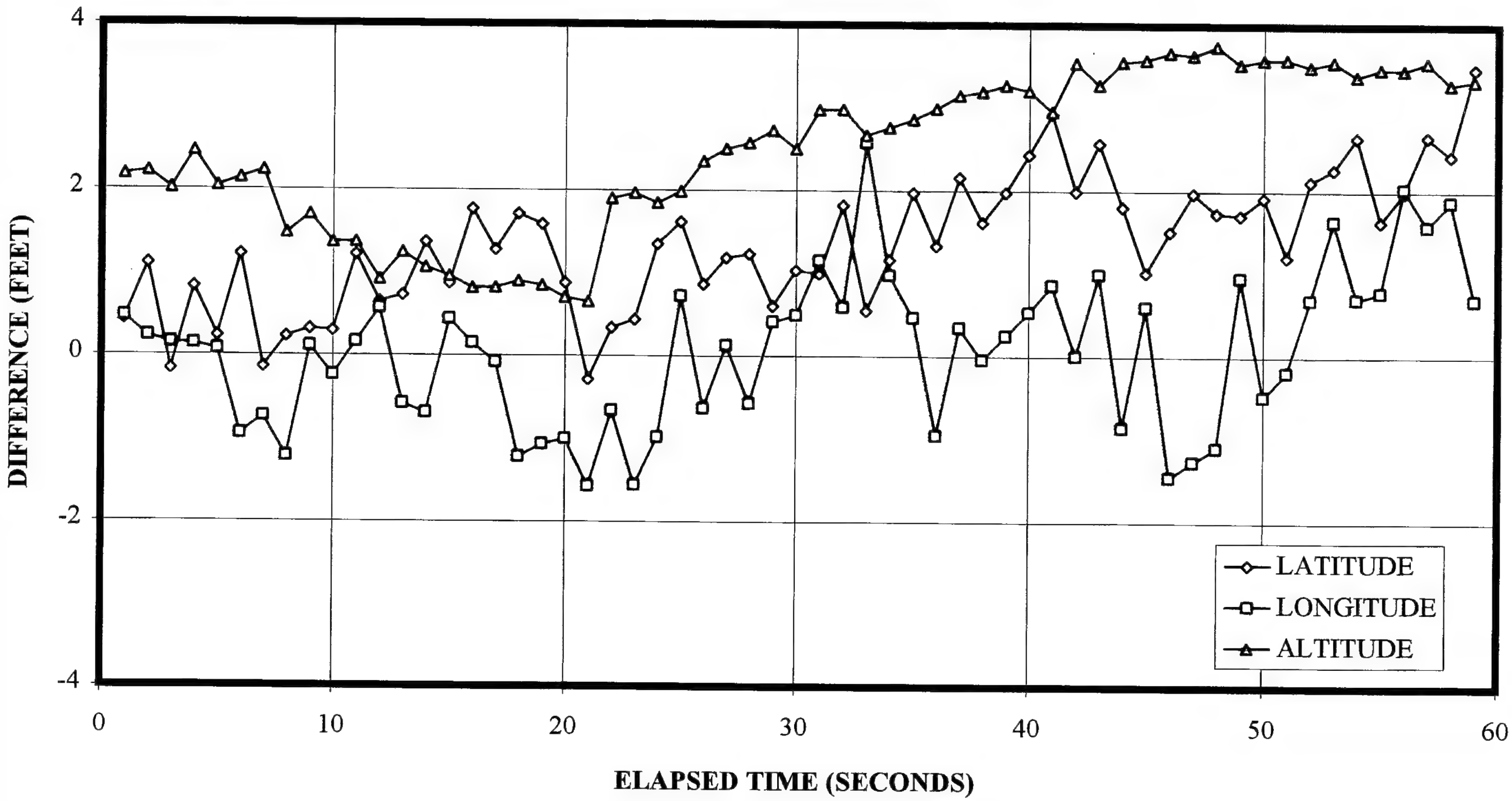
REAL-TIME GPS vs OPTICS
PASS # 11 - 15 DEGREE BANK
8 JUNE 1995 - WSMR



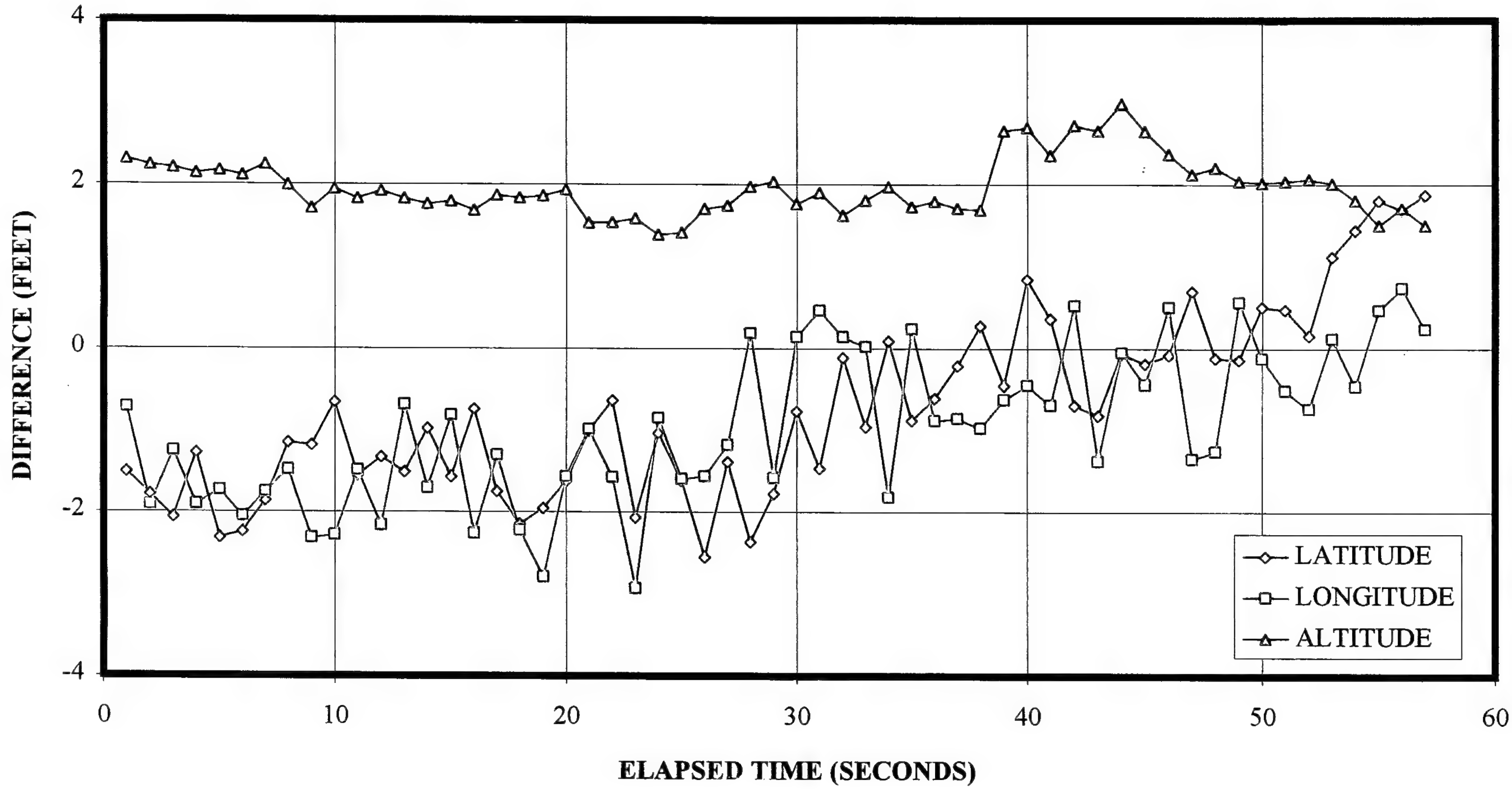
REAL-TIME GPS vs OPTICS
PASS # 12 - 30 DEGREE BANK
8 JUNE 1995 - WSMR



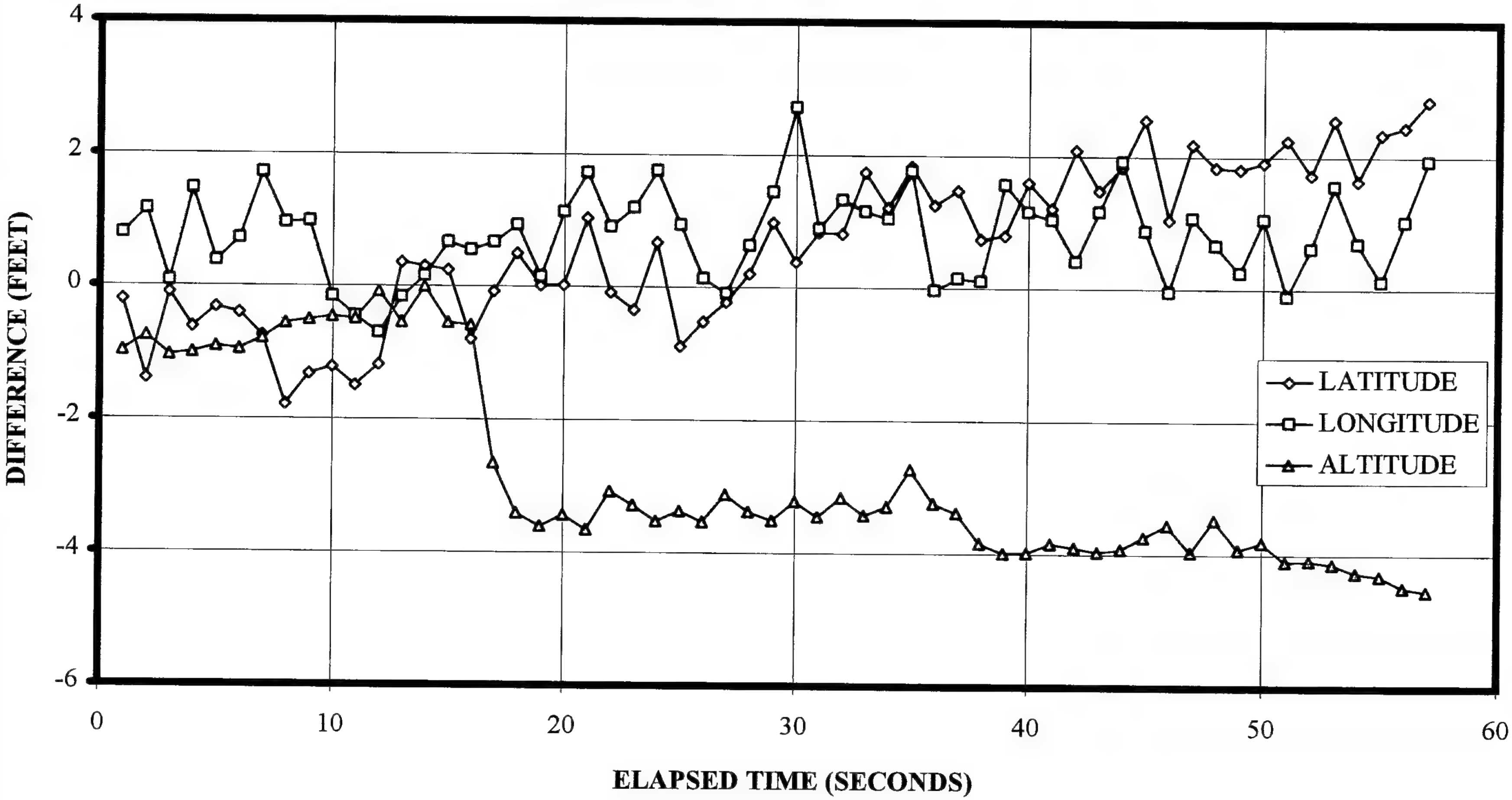
REAL-TIME GPS vs OPTICS
PASS # 13 - 45 DEGREE BANK
8 JUNE 1995 - WSMR



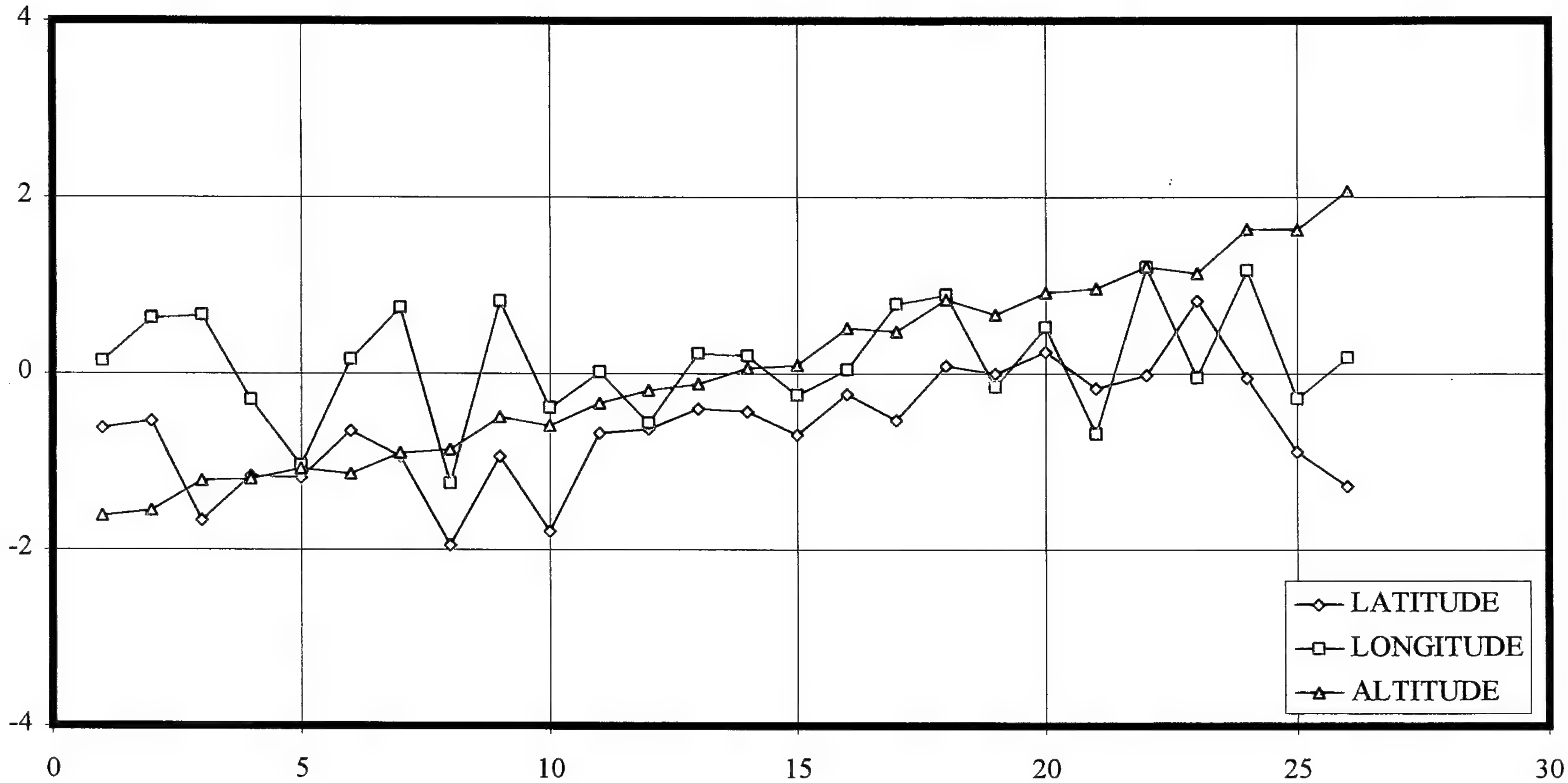
REAL-TIME GPS vs OPTICS
PASS # 14 - 60 DEGREE BANK
8 JUNE 1995 - WSMR



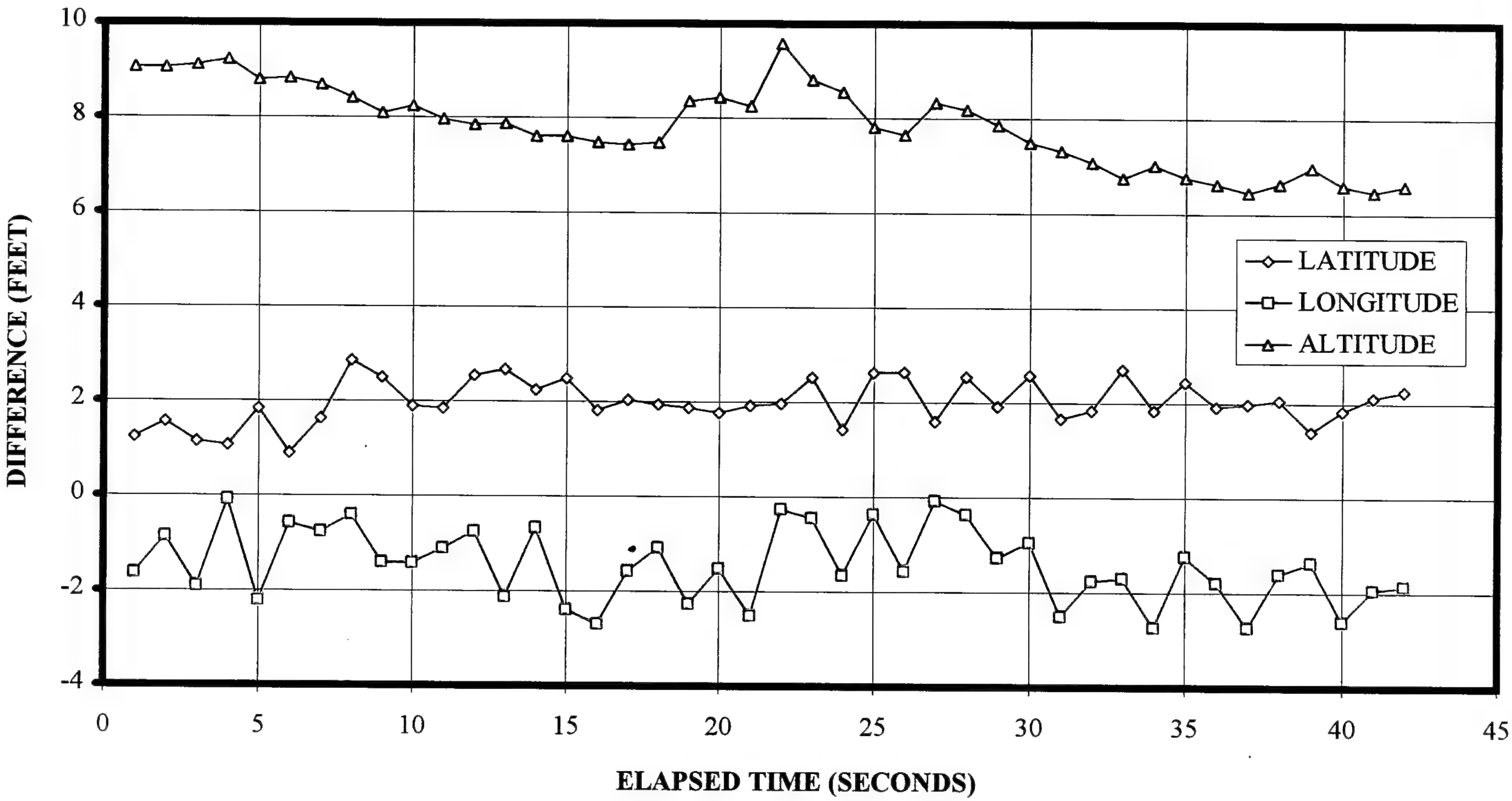
REAL-TIME GPS vs OPTICS
PASS # 15 - FIGURE EIGHT
8 JUNE 1995 - WSMR



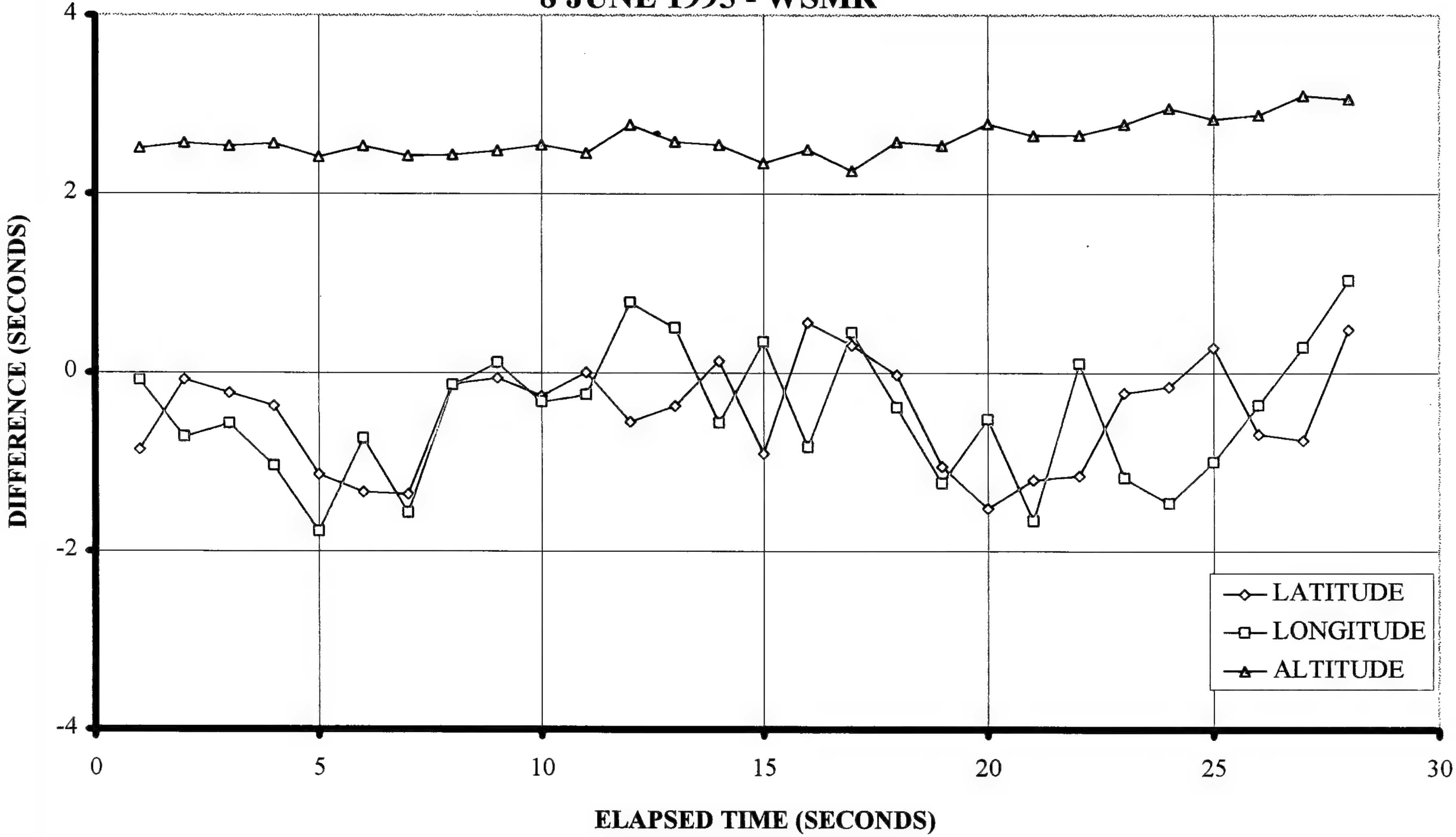
REAL-TIME GPS vs OPTICS
PASS # 16 - LEVEL FLIGHT
8 JUNE 1995 - WSMR

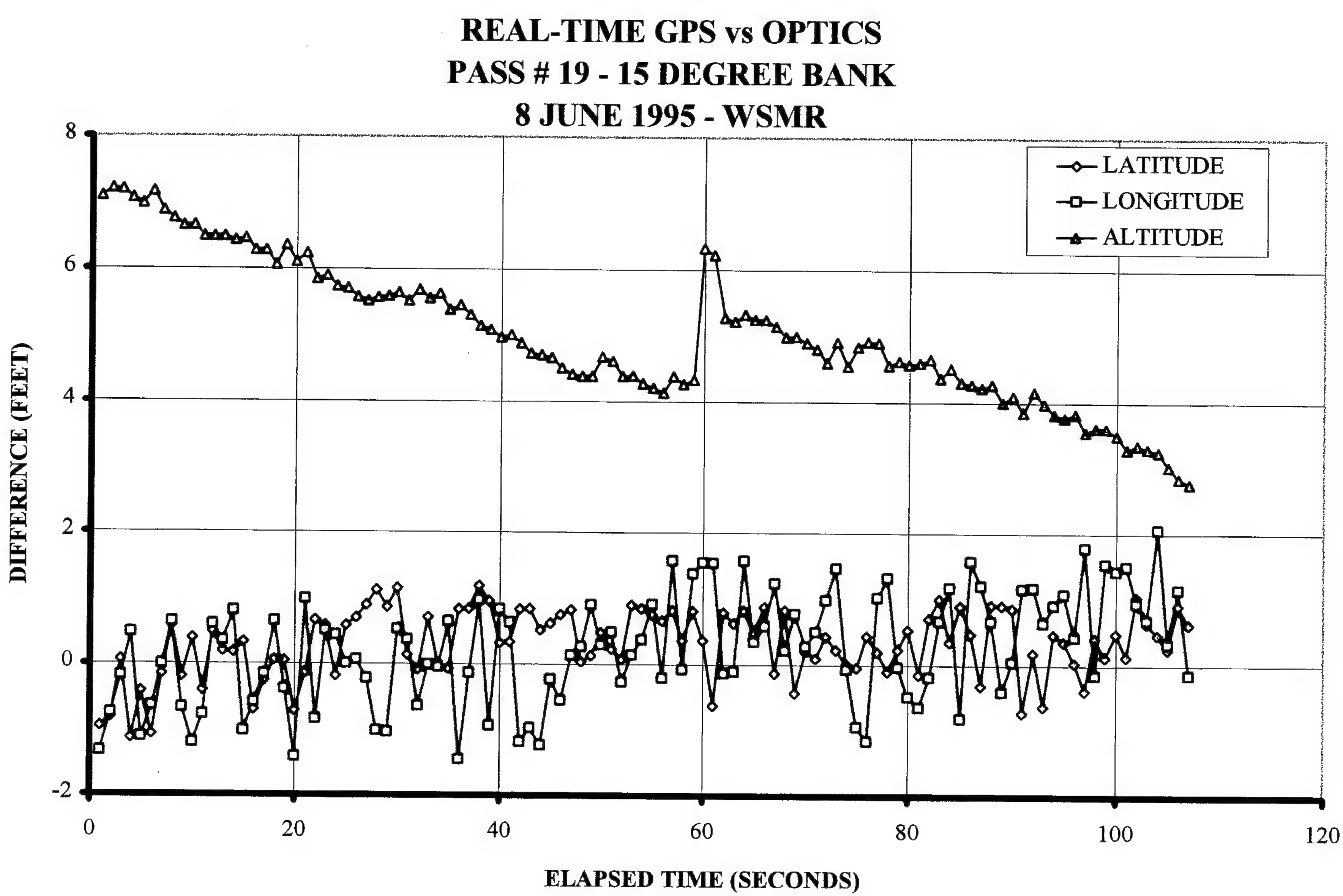


REAL-TIME GPS vs OPTICS
PASS # 17 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR

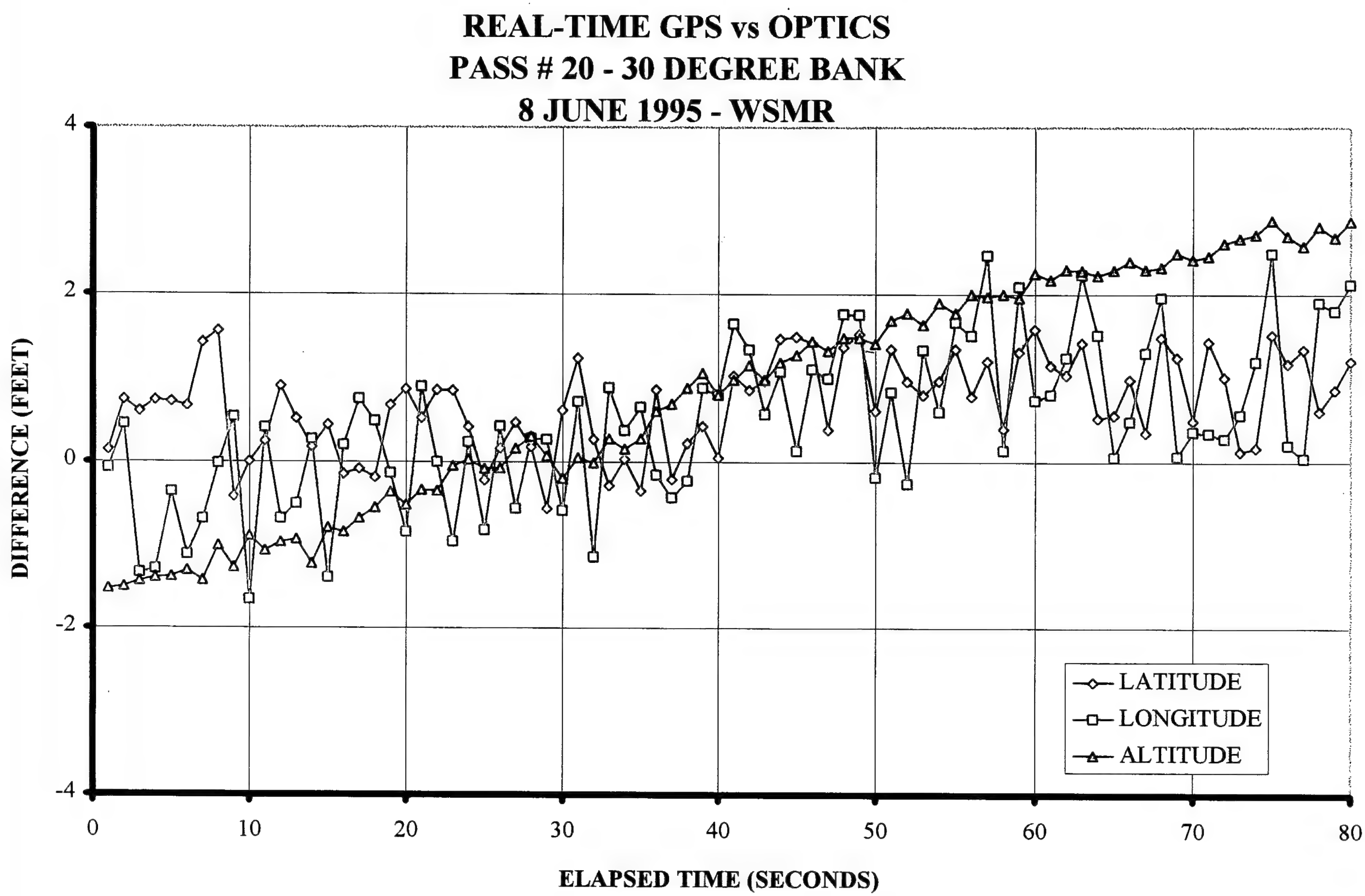


REAL-TIME GPS vs OPTICS
PASS # 18 - LEVEL FLIGHT
8 JUNE 1995 - WSMR





REAL-TIME GPS vs OPTICS
PASS # 19 - 15 DEGREE BANK
8 JUNE 1995 - WSMR
LATITUDE
LONGITUDE
ALTITUDE
DIFFERENCE (FEET)
8
6
4
2
0
-2
0
20
40
60
80
100
120
ELAPSED TIME (SECONDS)


REAL-TIME GPS vs OPTICS
PASS # 20 - 30 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

APPENDIX E. SUMMARY OF STATISTICS FOR POSTMISSION AND REAL-TIME PROCESSED DATA

POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS	AVERAGE LATITUDE DIFFERENCE (FEET) LAT	STD DEV LATITUDE DIFFERENCE (FEET)	MAXIMUM LATITUDE DIFFERENCE (FEET)	MINIMUM LATITUDE DIFFERENCE (FEET)
65943.5	13.5	1	26	0.675	0.432	1.426	-0.364
66046.5	116.5	2	50	0.528	0.471	1.749	-0.369
66257.4	327.4	3	125	0.160	0.587	2.057	-1.163
66442.0	512.0	4	95	-0.438	0.729	1.433	-2.114
66601.0	671.0	5	77	-0.380	0.865	1.572	-2.763
66740.5	810.5	6	64	0.043	0.828	2.241	-1.493
66906.0	976.0	7	107	-0.430	1.004	4.454	-2.603
67052.0	1122.0	8	31	0.716	0.695	2.404	-0.805
67172.0	1242.0	9	37	-0.723	0.475	0.201	-1.510
67289.5	1359.5	10	26	0.285	0.514	1.897	-0.480
67443.5	1513.5	11	102	-0.330	0.763	1.353	-2.377
67646.5	1716.5	12	76	0.286	0.630	1.705	-1.155
67817.0	1887.0	13	59	0.146	0.999	2.667	-1.848
67951.0	2021.0	14	57	0.023	1.095	2.529	-1.848
68080.0	2150.0	15	57	-0.217	1.015	1.976	-2.179
68235.5	2305.5	16	26	1.224	0.608	2.486	0.002
68376.5	2446.5	17	42	-1.388	0.441	-0.506	-2.427
68508.5	2578.5	18	28	0.904	0.686	2.165	-0.361
68725.0	2795.0	19	107	-0.567	0.612	0.811	-2.183
68940.5	3010.5	20	80	-0.281	0.654	1.121	-1.683

POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS	AVERAGE LONGITUDE DIFFERENCE (FEET) LONG	STD DEV LONGITUDE DIFFERENCE (FEET)	MAXIMUM LONGITUDE DIFFERENCE (FEET)	MINIMUM LONGITUDE DIFFERENCE (FEET)
65943.5	13.5	1	26	0.434	0.782	2.387	-0.859
66046.5	116.5	2	50	-0.903	0.674	0.469	-1.949
66257.4	327.4	3	125	-0.549	0.725	1.035	-2.097
66442.0	512.0	4	95	-0.382	0.905	1.542	-2.291
66601.0	671.0	5	77	-0.140	0.796	1.992	-1.537
66740.5	810.5	6	64	-0.262	0.909	1.703	-1.616
66906.0	976.0	7	107	-0.317	0.754	1.517	-1.831
67052.0	1122.0	8	31	-0.522	0.521	0.733	-1.387
67172.0	1242.0	9	37	-0.404	0.790	0.784	-1.834
67289.5	1359.5	10	26	0.237	0.650	1.344	-1.027
67443.5	1513.5	11	102	-0.550	0.718	1.144	-2.054
67646.5	1716.5	12	76	-0.237	0.793	1.612	-1.850
67817.0	1887.0	13	59	0.012	0.957	2.547	-1.523
67951.0	2021.0	14	57	-0.296	0.817	1.265	-2.028
68080.0	2150.0	15	57	-0.223	0.798	1.924	-2.203
68235.5	2305.5	16	26	0.511	0.649	1.603	-0.959
68376.5	2446.5	17	42	0.137	0.727	1.272	-1.107
68508.5	2578.5	18	28	0.757	0.768	2.303	-0.545
68725.0	2795.0	19	107	0.332	0.762	2.004	-1.344
68940.5	3010.5	20	80	0.301	0.761	1.791	-1.031

POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS	AVERAGE ALTITUDE DIFFERENCE (FEET) ALT	STD DEV ALTITUDE DIFFERENCE (FEET)	MAXIMUM ALTITUDE DIFFERENCE (FEET)	MINIMUM ALTITUDE DIFFERENCE (FEET)
65943.5	13.5	1	26	-0.160	0.116	0.123	-0.333
66046.5	116.5	2	50	2.345	0.485	3.122	1.353
66257.4	327.4	3	125	1.996	0.482	3.460	1.424
66442.0	512.0	4	95	1.793	0.351	2.439	1.033
66601.0	671.0	5	77	0.361	0.459	1.665	-0.287
66740.5	810.5	6	64	0.800	0.411	1.669	0.031
66906.0	976.0	7	107	0.336	0.337	1.150	-0.427
67052.0	1122.0	8	31	0.971	0.299	1.500	0.357
67172.0	1242.0	9	37	0.708	0.356	1.370	-0.110
67289.5	1359.5	10	26	1.014	0.315	1.630	0.373
67443.5	1513.5	11	102	-0.137	0.326	0.721	-0.711
67646.5	1716.5	12	76	0.758	0.206	1.283	0.247
67817.0	1887.0	13	59	0.036	0.362	0.670	-0.830
67951.0	2021.0	14	57	0.606	0.413	1.380	-0.240
68080.0	2150.0	15	57	0.885	0.393	1.607	0.107
68235.5	2305.5	16	26	0.295	0.100	0.493	0.137
68376.5	2446.5	17	42	-1.395	0.209	-0.973	-1.747
68508.5	2578.5	18	28	0.393	0.225	0.793	0.057
68725.0	2795.0	19	107	-1.274	0.379	-0.439	-1.940
68940.5	3010.5	20	80	-0.827	0.320	-0.059	-1.425

POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS		LINEAR ERROR PROBABLE (VERTICAL)	CIRCULAR ERROR PROBABLE (HORIZONTAL)	SPHERICAL ERROR PROBABLE
65943.5	13.5	1	26		0.078039732	0.714985639	0.681347702
66046.5	116.5	2	50		0.327187579	0.67410201	0.835131309
66257.4	327.4	3	125		0.325029377	0.772653027	0.91923046
66442.0	512.0	4	95		0.236835291	0.961630183	1.01661308
66601.0	671.0	5	77		0.309699137	0.97762084	1.085901475
66740.5	810.5	6	64		0.277274789	1.022500308	1.100304108
66906.0	976.0	7	107		0.227095599	1.034909478	1.072963901
67052.0	1122.0	8	31		0.201801787	0.715785187	0.77610247
67172.0	1242.0	9	37		0.240425908	0.744766339	0.830670404
67289.5	1359.5	10	26		0.212432111	0.685129904	0.757511421
67443.5	1513.5	11	102		0.220204808	0.87194796	0.925950379
67646.5	1716.5	12	76		0.139142448	0.837573963	0.834437608
67817.0	1887.0	13	59		0.244114083	1.151812645	1.187603704
67951.0	2021.0	14	57		0.278667275	1.12560681	1.191065053
68080.0	2150.0	15	57		0.264780526	1.067357646	1.129834352
68235.5	2305.5	16	26		0.067207662	0.73991608	0.694804813
68376.5	2446.5	17	42		0.141082541	0.687586259	0.705422777
68508.5	2578.5	18	28		0.151887466	0.855983394	0.860140027
68725.0	2795.0	19	107		0.255918343	0.8087349	0.898097304
68940.5	3010.5	20	80		0.215897159	0.83303505	0.888822335
				MEANS:	0.220736181	0.864181881	0.919597734

REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS	AVERAGE LATITUDE DIFFERENCE (FEET) LAT	STD DEV LATITUDE DIFFERENCE (FEET)	MAXIMUM LATITUDE DIFFERENCE (FEET)	MINIMUM LATITUDE DIFFERENCE (FEET)
65943.5	13.5	1	26	-0.079	0.531	1.008	-1.091
66046.5	116.5	2	50	-0.351	0.531	0.839	-1.315
66257.4	327.4	3	125	-0.528	0.625	1.414	-1.915
66442.0	512.0	4	95	-0.682	1.072	1.846	-2.828
66601.0	671.0	5	77	-1.089	0.607	0.087	-2.763
66740.5	810.5	6	64	-1.157	1.136	1.586	-3.288
66906.0	976.0	7	107	-0.397	1.012	4.515	-2.372
67052.0	1122.0	8	31	0.800	0.684	2.452	-0.660
67172.0	1242.0	9	37	-0.267	0.518	0.699	-1.255
67289.5	1359.5	10	26	0.280	0.505	1.775	-0.456
67443.5	1513.5	11	102	1.418	0.623	2.409	-0.521
67646.5	1716.5	12	76	-1.272	0.988	1.062	-3.187
67817.0	1887.0	13	59	1.362	0.814	3.479	-0.291
67951.0	2021.0	14	57	-0.733	1.119	1.874	-2.549
68080.0	2150.0	15	57	0.653	1.209	2.849	-1.779
68235.5	2305.5	16	26	-0.626	0.645	0.825	-1.950
68376.5	2446.5	17	42	1.983	0.479	2.841	0.896
68508.5	2578.5	18	28	-0.447	0.596	0.568	-1.518
68725.0	2795.0	19	107	0.319	0.523	1.188	-1.128
68940.5	3010.5	20	80	0.702	0.557	1.590	-0.555

REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS	AVERAGE LONGITUDE DIFFERENCE (FEET) LONG	STD DEV LONGITUDE DIFFERENCE (FEET)	MAXIMUM LONGITUDE DIFFERENCE (FEET)	MINIMUM LONGITUDE DIFFERENCE (FEET)
65943.5	13.5	1	26	-2.943	0.950	-0.542	-4.713
66046.5	116.5	2	50	-2.352	1.060	-0.080	-4.252
66257.4	327.4	3	125	-1.935	0.990	0.773	-3.541
66442.0	512.0	4	95	-0.871	0.790	0.853	-2.460
66601.0	671.0	5	77	-0.721	0.958	1.825	-2.398
66740.5	810.5	6	64	1.125	0.988	2.946	-0.536
66906.0	976.0	7	107	-1.603	0.724	0.248	-2.981
67052.0	1122.0	8	31	0.168	0.535	1.267	-0.752
67172.0	1242.0	9	37	-0.652	0.822	0.851	-2.050
67289.5	1359.5	10	26	-0.876	0.588	0.142	-1.982
67443.5	1513.5	11	102	0.494	0.908	2.500	-1.818
67646.5	1716.5	12	76	-0.264	0.868	1.428	-2.240
67817.0	1887.0	13	59	0.068	0.937	2.578	-1.582
67951.0	2021.0	14	57	-0.966	0.942	0.745	-2.932
68080.0	2150.0	15	57	0.804	0.681	2.723	-0.698
68235.5	2305.5	16	26	0.132	0.637	1.204	-1.247
68376.5	2446.5	17	42	-1.459	0.783	-0.085	-2.756
68508.5	2578.5	18	28	-0.456	0.751	1.039	-1.778
68725.0	2795.0	19	107	0.237	0.849	2.066	-1.455
68940.5	3010.5	20	80	0.460	0.961	2.491	-1.659

REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS	AVERAGE ALTITUDE DIFFERENCE (FEET) ALT	STD DEV ALTITUDE DIFFERENCE (FEET)	MAXIMUM ALTITUDE DIFFERENCE (FEET)	MINIMUM ALTITUDE DIFFERENCE (FEET)
65943.5	13.5	1	26	2.678	1.003	4.413	0.858
66046.5	116.5	2	50	8.525	0.941	9.533	6.396
66257.4	327.4	3	125	4.738	2.311	7.392	-1.105
66442.0	512.0	4	95	0.025	1.043	2.348	-1.472
66601.0	671.0	5	77	4.252	1.747	8.257	1.588
66740.5	810.5	6	64	1.602	1.348	3.777	-0.910
66906.0	976.0	7	107	2.264	1.215	4.194	-0.497
67052.0	1122.0	8	31	3.192	0.208	3.630	2.718
67172.0	1242.0	9	37	4.585	0.371	5.332	3.716
67289.5	1359.5	10	26	0.600	0.170	0.965	0.307
67443.5	1513.5	11	102	2.852	0.737	4.172	0.318
67646.5	1716.5	12	76	-0.945	0.605	0.301	-2.206
67817.0	1887.0	13	59	2.485	0.973	3.752	0.643
67951.0	2021.0	14	57	1.967	0.351	2.978	1.382
68080.0	2150.0	15	57	-2.800	1.419	-0.006	-4.548
68235.5	2305.5	16	26	0.031	1.067	2.067	-1.619
68376.5	2446.5	17	42	7.835	0.861	9.568	6.450
68508.5	2578.5	18	28	2.618	0.208	3.103	2.259
68725.0	2795.0	19	107	5.034	1.068	7.214	2.767
68940.5	3010.5	20	80	0.813	1.403	2.890	-1.527

REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

AVERAGE TIME	ELAPSED TIME FROM START (SEC)	RUN NO	NUMBER OF POINTS		LINEAR ERROR PROBABLE REALTIME	CIRCULAR ERROR PROBABLE REALTIME	SPHERICAL ERROR PROBABLE REALTIME
65943.5	13.5	1	26		0.676407751	0.872006199	1.272715284
66046.5	116.5	2	50		0.634858911	0.936682341	1.297406409
66257.4	327.4	3	125		1.559048257	0.950649799	2.011942
66442.0	512.0	4	95		0.703671286	1.096481857	1.488729393
66601.0	671.0	5	77		1.17805855	0.921671376	1.697178595
66740.5	810.5	6	64		0.909120351	1.250180721	1.778588694
66906.0	976.0	7	107		0.819521977	1.022315884	1.512251522
67052.0	1122.0	8	31		0.140545361	0.717429092	0.730977784
67172.0	1242.0	9	37		0.249903405	0.789018198	0.876372421
67289.5	1359.5	10	26		0.114619303	0.643296269	0.646778424
67443.5	1513.5	11	102		0.497197323	0.901096564	1.161823976
67646.5	1716.5	12	76		0.407782068	1.092630086	1.260502546
67817.0	1887.0	13	59		0.656600321	1.031035737	1.396017335
67951.0	2021.0	14	57		0.23668427	1.213276251	1.235430384
68080.0	2150.0	15	57		0.957151737	1.112757584	1.695534418
68235.5	2305.5	16	26		0.719701123	0.755180363	1.20397977
68376.5	2446.5	17	42		0.581033548	0.742684439	1.087720959
68508.5	2578.5	18	28		0.140504123	0.792844588	0.796557926
68725.0	2795.0	19	107		0.720590173	0.808096909	1.250692842
68940.5	3010.5	20	80		0.946389172	0.893481899	1.496585023
				MEANS:	0.64246945	0.927140808	1.294889285

APPENDIX F. ABBREVIATIONS

app	- appendix
ATTC	- U.S. Army Aviation Technical Test Center
fig.	- figure
GPS	- global positioning system
GMT	- Greenwich mean time
IAW	- in accordance with
No.	- number
RMS	- root mean square
SEP	- spherical error probable
TDARDS	- Truth Data Acquisition Recording And Display System
TSPI	- time-space positioning information
TECOM	- U.S. Army Test and Evaluation Command
WSMR	- White Sands Missile Range

APPENDIX G. DISTRIBUTION LIST

ADDRESSEES	REPORT
Commander	
U.S. Army Test and Evaluation Command	
ATTN: AMSTE-CT-T	3
AMSTE-TA-L	1
Aberdeen Proving Ground, MD 21005-5055	
Commander	
White Sands Missile Range	
ATTN: STEWS-TD-P	1
NRO-DR-S (Mr. Tony Palomino)	1
White Sands Missile Range, NM 88002	
Defense Technical Information Center	1
8725 John J. Kingman Road, Suite 0944	
Fort Belvoir, VA 22060-6218	